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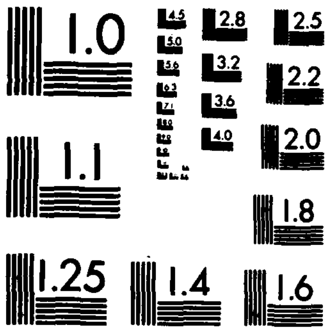

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HYBRID VEHICLE SIMULATION

THESIS

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HYBRID VEHICLE SIMULATION

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

David B. Founds, B. S.
First Lieutenant USAF

Graduate Aeronautical Engineering

October 1983

Approved for public release; distribution unlimited.

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List of Symbols

BHP = Brake horse power

C = Celsius

CI = Combustion ignition

V = Voltage difference

hp = Horse power

hr = Hour

HVSIM = Computer program

in = Inches

ks = Kilograms

kwh = Kilowatt hour

min = Minute

MPH = Miles per hours

N = Engine revolutions per minute

R = Gear ratio or resistance

r = Rolling radius

RPM = Revolutions per minute

= Standard deviation

SI = Spark ignition

T = Torque

w = Watts

wh = Watt hour

Subscripts

BHP_{max} = maximum brake horsepower

RPM_{max} = maximum engine rpm

Abstract

Interest in nonpetroleum fueled ground vehicles led Stafford to develop the computer code, Electric Vehicle Simulation (EVSIM). EVSIM was designed to predict the performance of current electric vehicles or to be used in the design of electric/hybrid vehicles. Before EVSIM could be used, it needed to be verified by comparing its predictions to the results of a vehicle test. It was also desired to improve the code's ability to model several types of Internal Combustion Engines that may be used in hybrid vehicles. The approach taken was to test the components of the the hybrid vehicle separately prior to testing the whole vehicle. This was done to verify separate sections of EVSIM prior to a systems run. The results of these comparisons and the system comparison are included with recommended changes to EVSIM.

I. Introduction

Interest in alternatives to conventional petroleum fueled ground passenger vehicles in both the private and public sectors led to the development of the computer model, Electric Vehicle Simulation (EVSIM) by Stafford (Ref 21). EVSIM is capable of modeling hybrid (electric/internal combustion) powered vehicles. While this model was extensive it lacked modeling sophistication and sufficient validation in the areas of battery use and the auxilary internal combus on (IC) engine.

Background

EVSIM can be used to predict the performance of an existing electric or hybrid vehicle, or aid in the design of a new vehicle based on the performance desired (Ref 21). The output of the simulation includes such items as average cost of energy used per kilometer and the amount of battery consumed per cycle. This information taken with the estimated initial cost and maintenance cost can be used to establish economic levels of merit among various systems of interest. The vehicle model includes the effects of aerodynamic drag, rolling resistance, rotational and translational inertia, and power train efficiencies. The battery model used in the simulation was based on a fractional utilization algorithm with corrections for short term discharge effects for lead-acid deep cycle batteries. The driving cycle selected was the Federal Urban Driving Sequence (Ref 5). Provisions were made in the simulation to model an internal combustion engine/series motor, parallel hybrid system.

Objectives

The initial objective was to select and install an IC engine into an existing test vehicle. The engine had to be able to provide the required amount of power and still fit in the test vehicle with as few modifications to the engine or the test vehicle as possible.

The second objective was to use EVSIM to predict the performance of the test vehicle. These results could then be compared to the actual results obtained from the test vehicle to either validate the computer simulation or to point out the areas where further refinements of EVSIM were needed to improve its accuracy as a tool for the evaluation of hybrid systems.

Approach

To meet the first objective EVSIM was used to determine the power required from the internal combustion engine during high speed cruise. The engine speed required of the IC engine was determined by the reduction ratio between the electric motor and the electric clutch on the test vehicle With these constraints an appropriate IC engine was selected for testing. The IC engine was run on a dynamometer to determine its operating characteristics. The results from these tests were compared to the predictions of EVSIM and the manufacturer's specifications. A vehicle description and discussion of the engine selection is contained in Chapter two, the testing and modeling of the internal combustion engine is described in Chapter four.

A first step toward the second goal of validating EVSIM was to test the battery model in the computer simulation. To do this, battery discharge tests at both constant and cyclic discharge rates were run. The results of these tests were compared to the results predicted by the battery model in EVSIM. The results of the tests and a description of the battery model are in Chapter three.

By testing the batteries and the IC engine separate from the rest of the vehicle, inaccuracies in EVSIM caused by the method in which they were modeled could be separated from those introduced by other parts of the simulation.

The IC engine and the magnetic clutch were installed in the test vehicle and the instrumentation needed for the vehicle test was selected. With the IC engine and instrumentation installed, the vehicle was tested in the all electric and the gas/electric hybrid mode. The results and comparisons of these tests and the performance predictions from EVSIM are presented in Chapter five.

II. Vehicle Design

In order to select vehicle components the performance goals and physical constraints on the test vehicle had to be identified. These goals and constraints would serve to guide the component selection.

Performance Goals

While EVSIM is flexible enough to model a wide array of hybrid systems, the vehicle seen as the target size for this study was a small four passenger sedan (Ref 21). This type of vehicle is used by the USAF for a variety of on and off base missions. The performance goals listed in Table I were established for this type of vehicle based on the desires of USAF vehicle managers (Ref 16) and the analysis of some off base mission requirements. The 90 km/hr top speed with 80 km/hr cruise allows limited suburban use. The 0 to 50 km/hr acceleration requirement meets the demands of typical urban driving (Ref 14). For a vehicle with a mass of 1200 kg and a frontal area of 1.9 m^2, published data (Refs 11,13) indicate that 12 kw of motor power are required to achieve the goal of 90 km/hr and that 22 kw of power are needed to reach the 0 to 50 km/hr acceleration requirement. The critical factor in electric vehicle design is the total energy storage capacity, not the maximum power available (Ref 8). The estimated power requirement of 10.5 kw of power for the 80 km/hr cruise times the two hour cruise requirement results in an estimate of 21 kwh of energy storage required. These power and energy requirements became important criteria for component selection.

TABLE I

Performance Requirements

Payload	4 Passengers (270 kg)
Top Speed	90 km/hr
Acceleration 0 to 50 km/hr	15 sec
Range	
Urban	80 km
80 km/hr cruise	160 km

Battery Selection

While the vehicle had to meet the performance requirements of the previous section it was also constrained to use readily available components. This constraint of availability ruled out a number of battery types (such as zinc-chloride and sodium-sulfur) despite their potential high performance (Refs 7, 8, 14, 17) due to their current lack of development and non-availability.

In lead-acid batteries the goals of high energy density and high power density can be achieved in a compromise simultaneously (Refs 12, 17). Standard automotive batteries have high power densities (up to 200 w/kg during starting, Ref 14) but lack the ability to recover from repeated deep cycles. Industrial batteries are designed for use in applications where size and weight constraints are not critical and the maximum power demand is not much above the average demand. They can sustain up to 2000 cycles but have power densities limited to below 20 w/kg (Ref 14). Golfcart batteries were developed to provide reasonable power densities (up to 100 w/kg) and still maintain deep-discharge life expectancies of 200 to 400 cycles (Refs 10, 14). These batteries represent the best trade-off in lead-acid batteries.

Both high power density and high energy density are, in theory, available from two nickel based batteries. However in recent tests nickel-zinc batteries have been unable to meet their expected performance and have shown poor deep-cycle performance (Ref 8). The nickel-iron battery has been demonstrated to have excellent deep cycle life (1000+ cycles) and high power densities (130 w/kg) with 25 percent higher energy density than lead-acid batteries. The problem with these batteries is that they have poor energy efficiency (typically 50 percent), about one third less than a lead-acid battery due to excessive hydrogen formation during charging. The most reasonable choice for batteries for a near term vehicle was the six volt golfcart battery, due to its availability and lack of disqualifing characteristics.

In determining the number of batteries to use in the vehicle the limiting constraint was the size of the vehicle chassis. The maximum number of batteries that could be installed in the vehicle and still maintain a four passenger capability was twelve. Based on a standard 29 kg, six volt battery this resulted in a 72 volt, 350 kg battery pack. The energy capacity of this system was found by multiplying the energy density of 30 wh/kg (Ref 14) by the mass of 350 kg to get 10.4 kwh. This result shows that in order to reach the two hour cruise goal, the battery mass alone could not provide the 21 kwh of energy needed. The IC portion of the hybrid would have to make up approximately half of the required energy used at cruise.

Hybrid Selection

The inability of the batteries to provide the total amount of energy needed to meet the goal of a two hour cruise led to the selection of a 6 kw electric motor (Ref 21). To provide the rest of the power needed for the 80 km/hr cruise an IC engine rated at approximately 7 hp was needed. With the size of the engine determined there were two possible arrangements of the IC-electric combination to consider.

The first gasoline-electric combination considered was a series hybrid system. In this system the IC engine drives a generator which supplies electricity to the electric motor directly or to the batteries, depending on the power required by the road load. The advantage of this configuration is the simplicity of the IC control, as the IC engine can be allowed to operate at its most efficient speed.

The disadvantages of this arrangement are the extra weight it requires and low efficiency. Assuming efficiencies of 85, 98, 70 and 96 percent for the engine, controller, generator, and engine/generator coupling respectively, it has been calculated that only 56 percent of the energy produced by the IC engine reaches the transmission (Ref 21). If the engine-generator pair are used to recharge the lead-acid batteries the efficiency is reduced by approximately another 25 percent due to losses in the recharging of lead-acid batteries (Ref 14). The reduction in efficiency is compounded by the extra weight added in the form of a larger IC engine needed to make up for the losses in the system and the generator needed to produce the electricity.

The second combination considered was a parallel hybrid system. In this combination the IC engine is coupled to the electric motor at the transmission. While the engine may not always be operating at its most efficient

speed, the losses in the system are reduced to those in the motor-engine coupling.

The parallel arrangement was selected for the test vehicle. Since the electric motor could apparently meet the acceleration demands, the main function of the IC engine was to meet the high speed cruise energy requirements. In addition to providing the extra energy needed for the high speed cruise, the proper use of the IC engine would reduce the motor current demand, which would increase the battery range. The coupling ratio selected was determined to allow high speed cruise in a relatively low transmission gear, allowing a high electric motor shaft speed, as this reduces the current demand in a series motor (Ref 21).

To facilitate the addition of a microprocessor control in a later study, it was decided that an electrically operated magnetic clutch should be used to couple the engine and motor. A parallel shaft V-belt drive was designed. V-belt designs have the advantage of high efficiency (96 percent) and low cost (Refs 19). The clutch selected was rated up to approximately 20 hp and had a diameter of 5 $^3/_4$ in. The speed required from the engine could now be determined from the rolling radius of the tires, the overall gear reduction of the test vehicle and the pulley size on the motor from the following equation (Ref 4).

$$RPM = \frac{168xRxMPH}{r} \quad (1)$$

Where RPM is the engine speed, R is the overall gear reduction ratio (both axle and transmission) times the engine/motor reduction ratio, MPH is the vehicle speed in miles per hour, and r is the rolling radius of the tires in inches. For the test vehicle during the 80 km/hr cruise in high gear

this resulted in:

$$RPM = \frac{168x10.1x49.7}{15.1} = 5585 \quad (2)$$

With the necessary power and speed range determined the next choice was what type of engine to use. There are four basic types of engines readily available: spark ignition four stroke cycle, spark ignition two stroke cycle and, two and four stroke cycle compression ignition engines. In general the following comparisons can be made between spark ignition (SI) and compression ignition (CI) engines:

(1) Power output per unit weight- The CI engine generally weighs five to twenty pounds or more per hp while the SI engine in general weighs one to seven pounds per hp.

(2) Power output per unit piston displacement- This factor can be used to roughly compare the size of the two engines. Most high speed CI engines will deliver about .3 hp per cubic inch of displacement, compared to .5 to .9 hp per cubic inch for SI engines. For this reason the SI engine will tend to occupy less space than a CI engine of the same hp rating.

(3) Acceleration- The CI engine will produce the best acceleration due to the use of fuel injection in this type of engine. The SI engine can overcome some of this disadvantage through the use of acceleration pumps.

(4) Reliability- In general the CI engine is built to stand rougher duty and is rated well below its maximum power output. This must be weighted against the SI engine's easier starting, particularly in cold weather.

(5) Fuel Economy- The single greatest advantage of the CI engine is its superior fuel economy at both full throttle (10 to 25 percent greater) and

at part throttle. The fuel used by the CI engine tends to be less expensive which also make the CI engine less costly to operate.

(6) Life cycle costs- The initial cost of CI engines tends to be greater than the initial cost of a comparable SI engine, although this may be offset by the longer life expectancy of the CI engine. The maintenance cost of the CI engine may be slighty higher than the SI engine.

(7) Operating speed- The SI engine tends to operate at higher speeds than the CI engine, 3000 to 5000 rpm for a typical SI engine compared to 1200 to 3000 rpm for a high speed CI engine (Ref 15).

(8) Miscellaneous considerations- The fuel used by the CI engine is less volatile and thus safer to use and the CI engine is better suited to two cycle operations. The exhaust from the SI engine tends to have a less objectionable odor but produces more CO.

The distinguishing feature of the two stroke cycle engine compared to the four stroke cycle engine is that there is one power stroke for every revolution of the crankshaft in the two stroke cycle engine. Whereas there is one power stroke for every other revolution of the crankshaft in the four stroke cycle engine. This would tend to indicate that a two stroke cycle engine could produce twice as much power as the same size four stroke cycle engine. Unfortunately, losses in power and efficiency occur during the scavenging process when exhaust gases are removed from the cylinder. In most SI two stroke cycle engines some of the fresh fuel and air mixture is lost pushing out the exhaust gases reducing the engines fuel efficiency. Spark ignition two stroke cycle engines tend to be limited to small engines where this fuel loss is not significant. In combustion ignition engines where the fuel is injected into the cylinder just before it is burned, fuel is not lost as only air is used in the scavenging process. The two stroke cycle engine also tends to be smaller and lighter than a comparable four stroke cycle

engine. Two stroke cycle engines also tend to be less expensive due to their simpler design (ref 18, 9).

In addition to having to provide the required 7 hp at 5 to 6 thousand rpm the engine selected for the test vehicle had to be able to fit in the limited space available for it. The space requirement ruled out the CI engines that were being considered. The choice left was between several two and four stroke cycle spark ignition engines. The two stroke cycle engines operated at their rated power output between 5 and 6 thousand rpm while the four stroke cycle engines operated at 3600 rpm. The two stroke cycle engines also had the advantage of weighting less than 15 pounds while the four stroke cycle engines weighted between 50 and 60 pounds. For these reasons an 8 hp, two stroke cycle spark ignition engine was chosen for the test vehicle.

Vehicle Description

The vehicle selected to test the EVSIM code was a light four passenger sedan. It had a frontal area of 1.8 meters square and a fixed mass of 325 kilograms. The original four speed transmission was used but the gasoline engine and fuel tank were replaced by a 6 kilowatt electric motor and 350 kilograms of batteries. The electric motor is controlled with a five step voltage switch. The final allowable payload mass after the conversion to electric power was 270 kilograms. The vehicle was also instrumented to measure the current demand, and RPM of the electric motor; the vehicle velocity; engine RPM; and the fuel flow to engine. Provisions were made to allow the inclusion of a microprocessor to control the vehicle and to acquire data.

III. Battery Simulation and Evaluation

The major problem in predicting the range and performance of electric and hybrid vehicles is the lack of accurate models of the batteries (Ref 21). The models used need to be improved and tested to determine their limitations.

Objective

The objective of this effort was to test the batteries used in the test vehicle and compare their performance to that predicted by the battery model used in HVSIM. The test results would be used to modify the battery model if necessary and determine the limitations of the battery model.

Background

The modeling of the batteries used in electric and electric hybrid vehicles is the most difficult problem in obtaining agreement between theory and practice. Compared to other components of the vehicle there is little experimental data and few analytical models. Some of the reasons for this lack of information include:

1. The lack of a need for analytical models in most past and present non-electric vehicle uses.

2. The electrochemical nature of batteries is more complex to model than the electromechanical nature of most of the vehicles' other components. Some electrochemical equations have been developed to describe the internal phenomena; the formidable task of relating these to the batteries external characteristics still remain.

3. There is a wide range of battery types and even within a single type, there is considerable variation in geometry, plate thickness, chemical reaction, and internal configuration.

4. Battery performance depends, in general, upon the charge/discharge history of the individual battery (Ref 22).

With these limitations in mind the battery model used in EVSIM was designed to represent lead-acid batteries only, and to take into account the discharge rates experienced by the batteries.

Battery Simulation

The energy available from a battery at constant load is primarily a function of the battery's discharge rate. Figure 3.1 is the discharge to capacity curve used to develop the model used in EVSIM. An equation relating the batteries capacity to its constant discharge rate and the temperature was developed and presented by Stafford (Ref 21). This equation was modified to take into account the effects of varying discharge rates. Combining this equation with one for the internal resistance of the batteries allows the terminal voltage of the battery to be estimated (Ref 21).

Model Verification

Five goals for the test were established to meet the objective of verifying the battery simulation and making any corrections needed. The first goal was to verify that the simulation could accurately model a battery being discharged at a constant rate. The second goal was to determine the effect that a temperature change has on the simulations accuracy. The third goal was to test the battery at varying discharge rates and compare the measured results to those predicted by the computer. The fourth goal

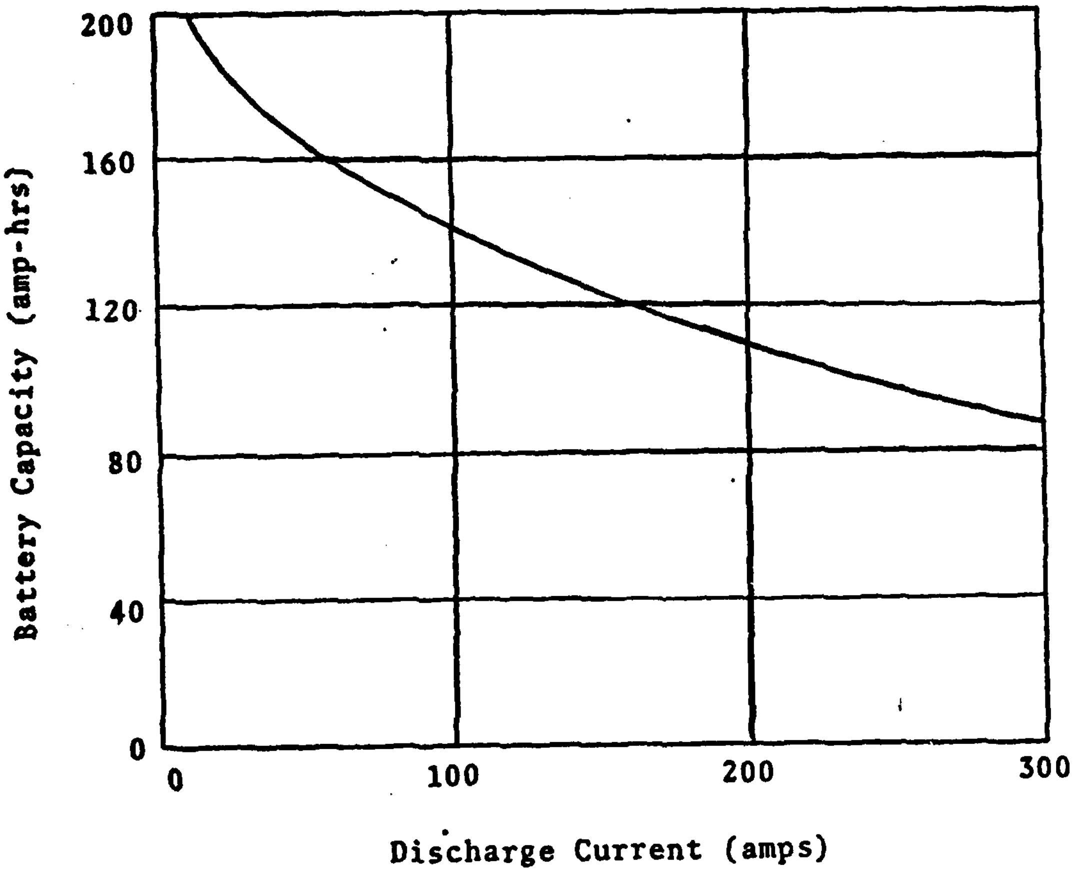


Figure 3.1 Lead-Acid Battery Discharge

was to measure the effect of the battery's self regeneration during a period of rest on its useful energy. The fifth goal was to determine the effect of overcharging a battery on its range.

A schematic of the test setup used is shown in figure 3.2. For the first series of tests to verify the simulation at a constant discharge rate the battery was discharged through constant resistor R1. The third goal was achieved by using a series of relays to change the value of R1 thereby varying the discharge rate. These tests were performed at 21°C and at 6°C to determine the effect of temperature on the simulation accuracies. The battery was overcharged by .3 volts to measure its effect on the useful energy.

Results

From the results of the constant discharge tests, it could be seen that the equations for constant discharge needed to be modified. Using Stafford's original data, a new set of equations were developed. When the new equations were used, the difference between the measured data and the predicted data fell from over 1 volt to less than .4 volts. Using these new equations the rest of the experimental data was compared to the battery simulation predictions. Table II lists the results of these comparisons. Figures 3.3 and 3.4 show results of typical constant rate discharge and a varying rate discharge respectively. Figures 3.5, 3.6, and 3.7 show the effects of discharge rate, temperature, and overcharging of the battery on the prediction accuracy. Figures 3.8 and 3.9 show the results if the simulation is based on discharge equations generated from the experimental data of test one. A complete description of the tests and their results are in Appendix A.

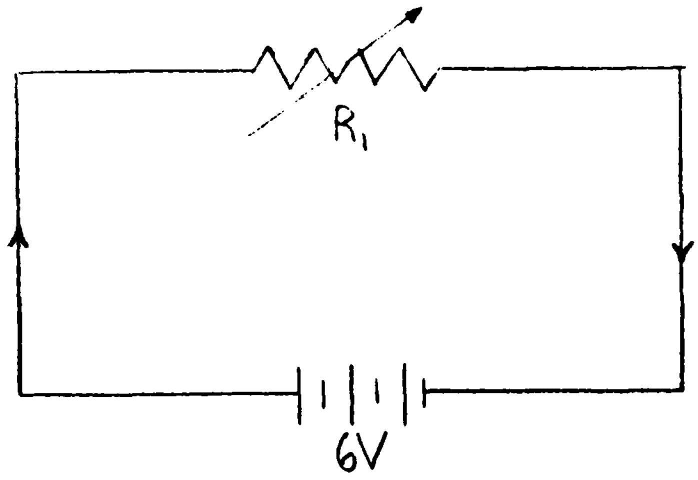


Figure 3.2 Battery Test Schematic

Conclusions

1. The battery model used in HVSIM can predict constant discharge battery performance within 10% of measured performance. The model tends to over predict the available energy.

2. The battery model predicts varying discharge rate performance within 10%.

3. Using the battery model based on the measured battery performance, the difference between measured and predicted performance was within 5% for constant or varying rate discharge.

4. The air temperature did not significantly affect the accuracy of the battery performance prediction.

5. The battery model was able to predict the effects of battery regeneration; however, regeneration will not significantly increase the range of hybrid vehicles.

6. The general voltage expression for a nominal six-volt battery given in EVSIM (Ref 21) should be replace with:

$$V_b = 6.09 - (.003)R_B{}^{*}I_B - (.36)DF^2$$

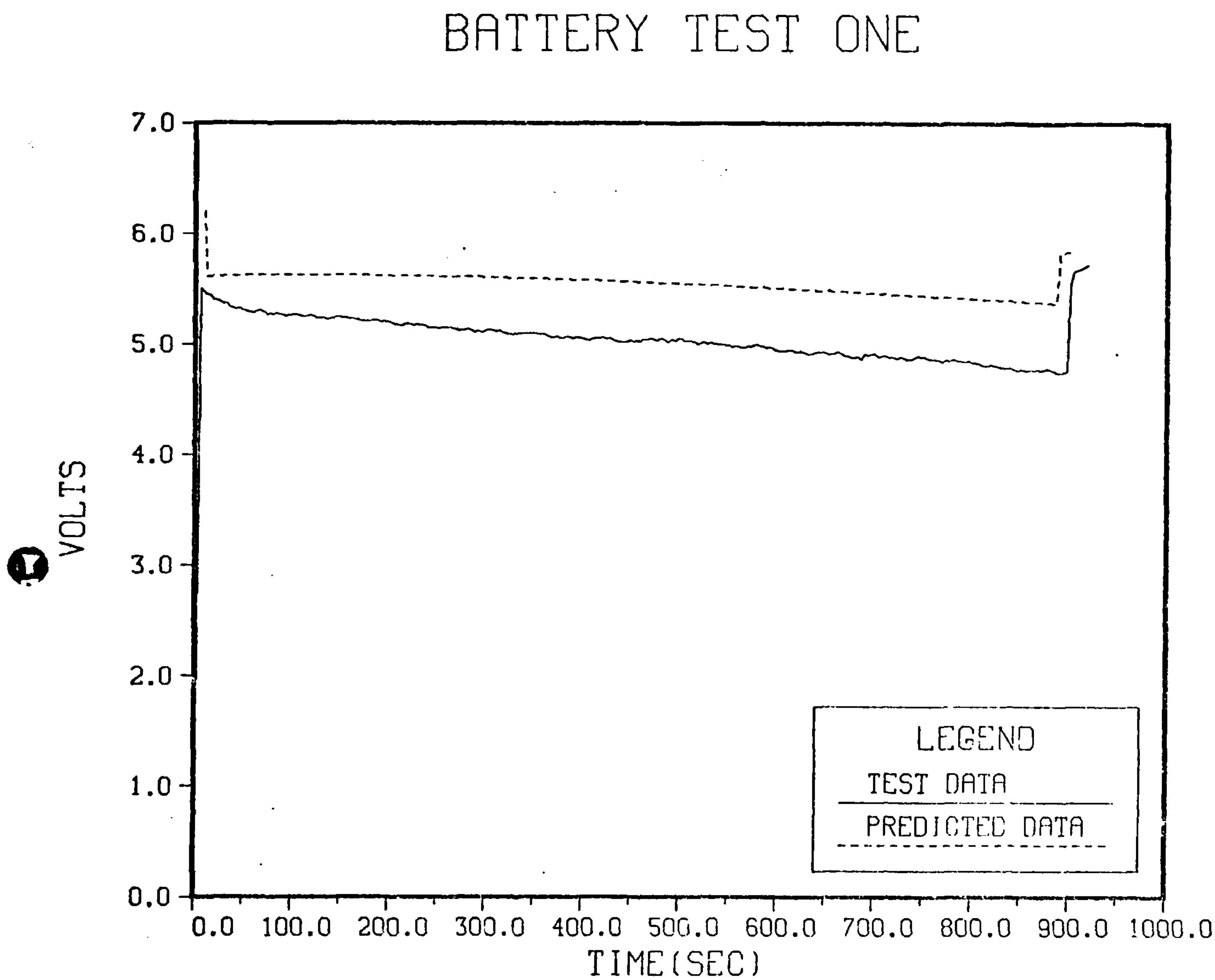


Figure 3.3 Constant Discharge Rate

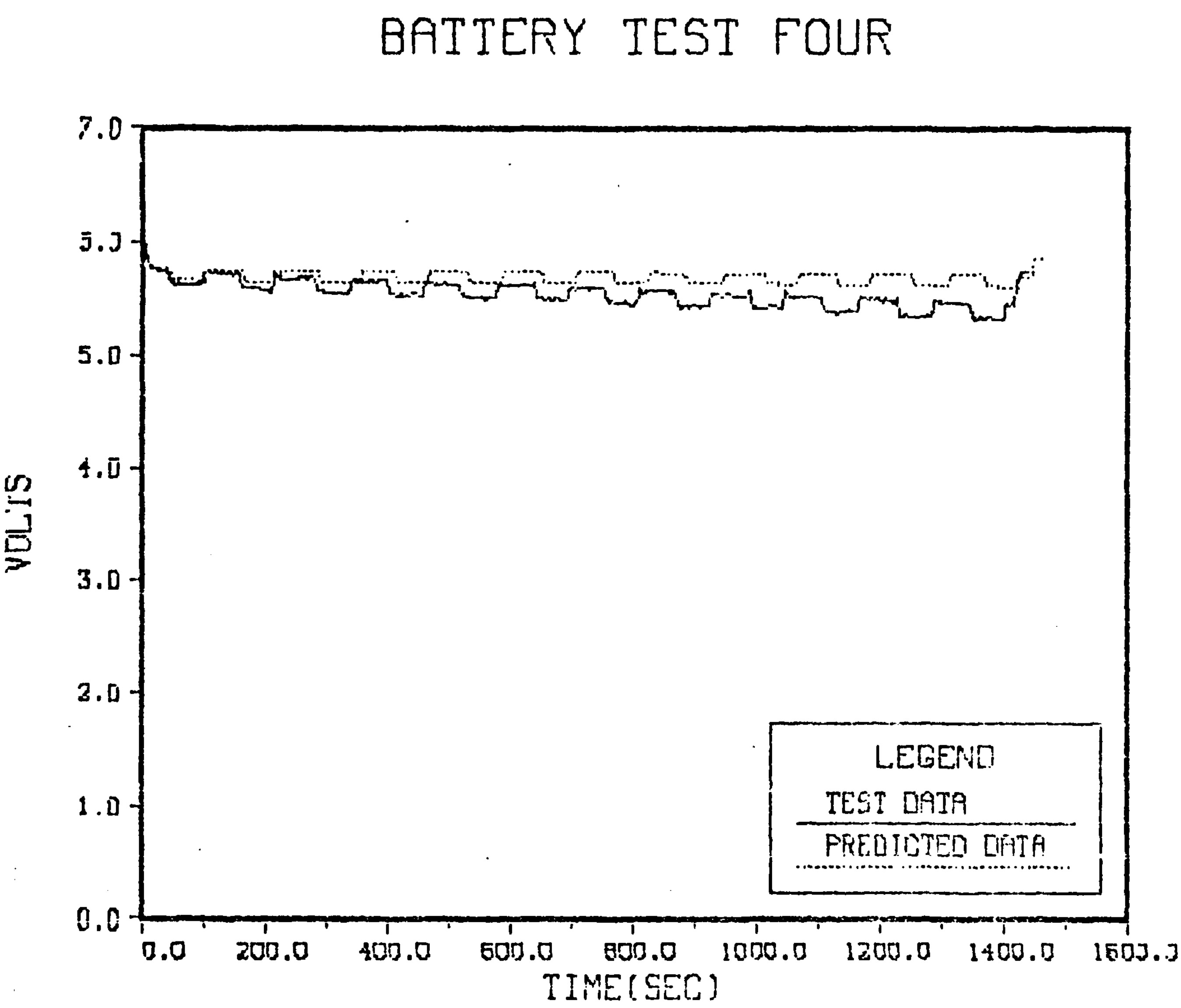


Figure 3.4 Varying Discharge Rate

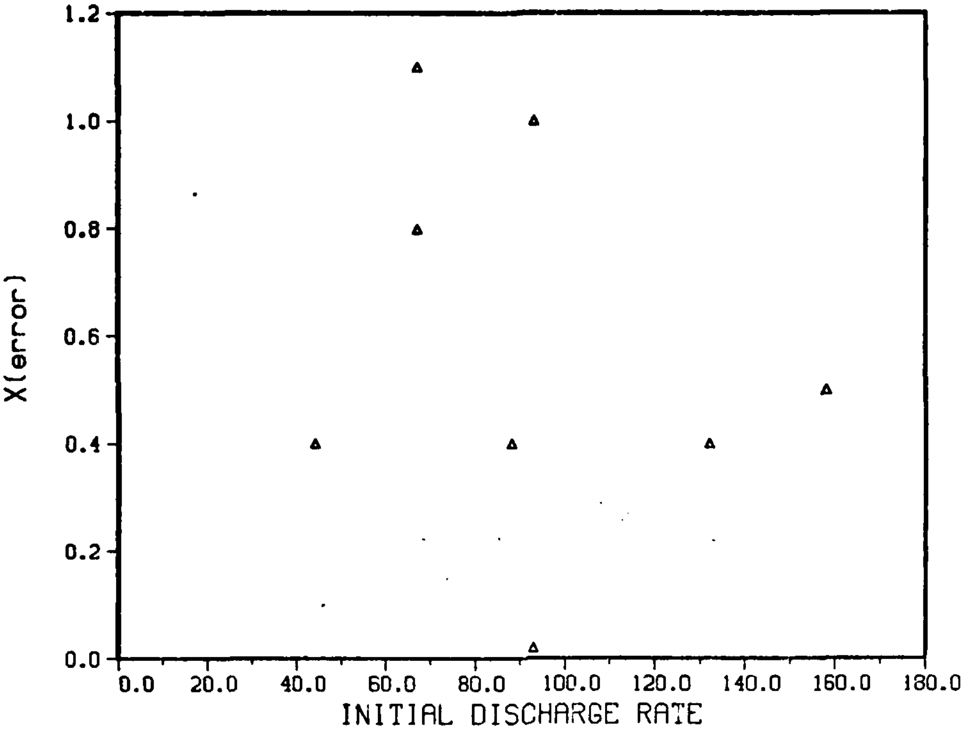


Figure 3.5

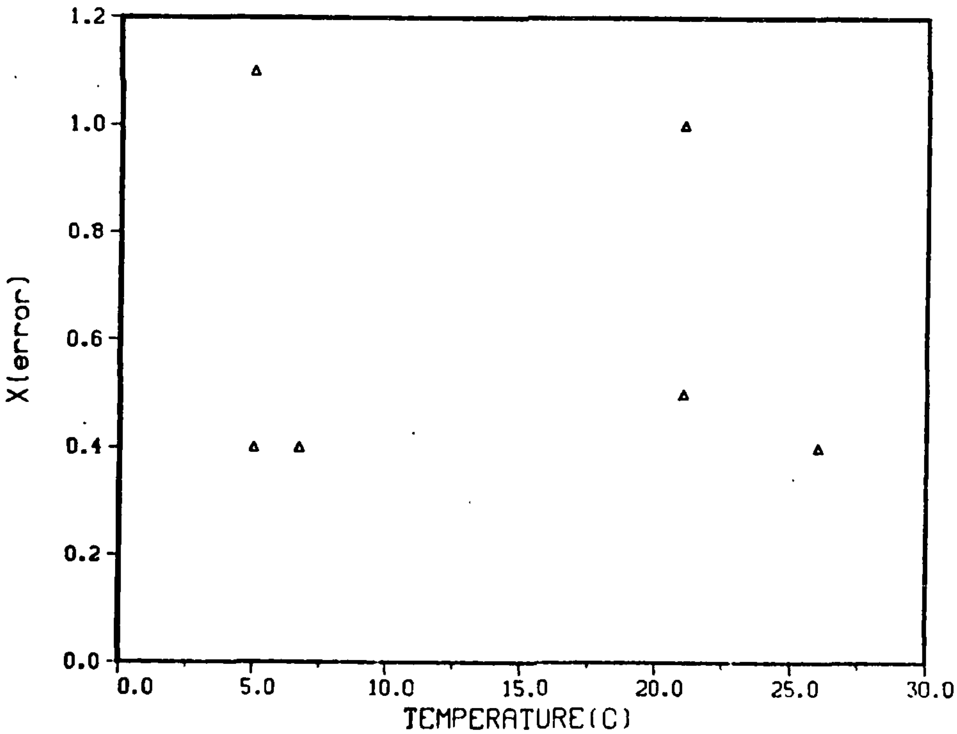


Figure 3.6

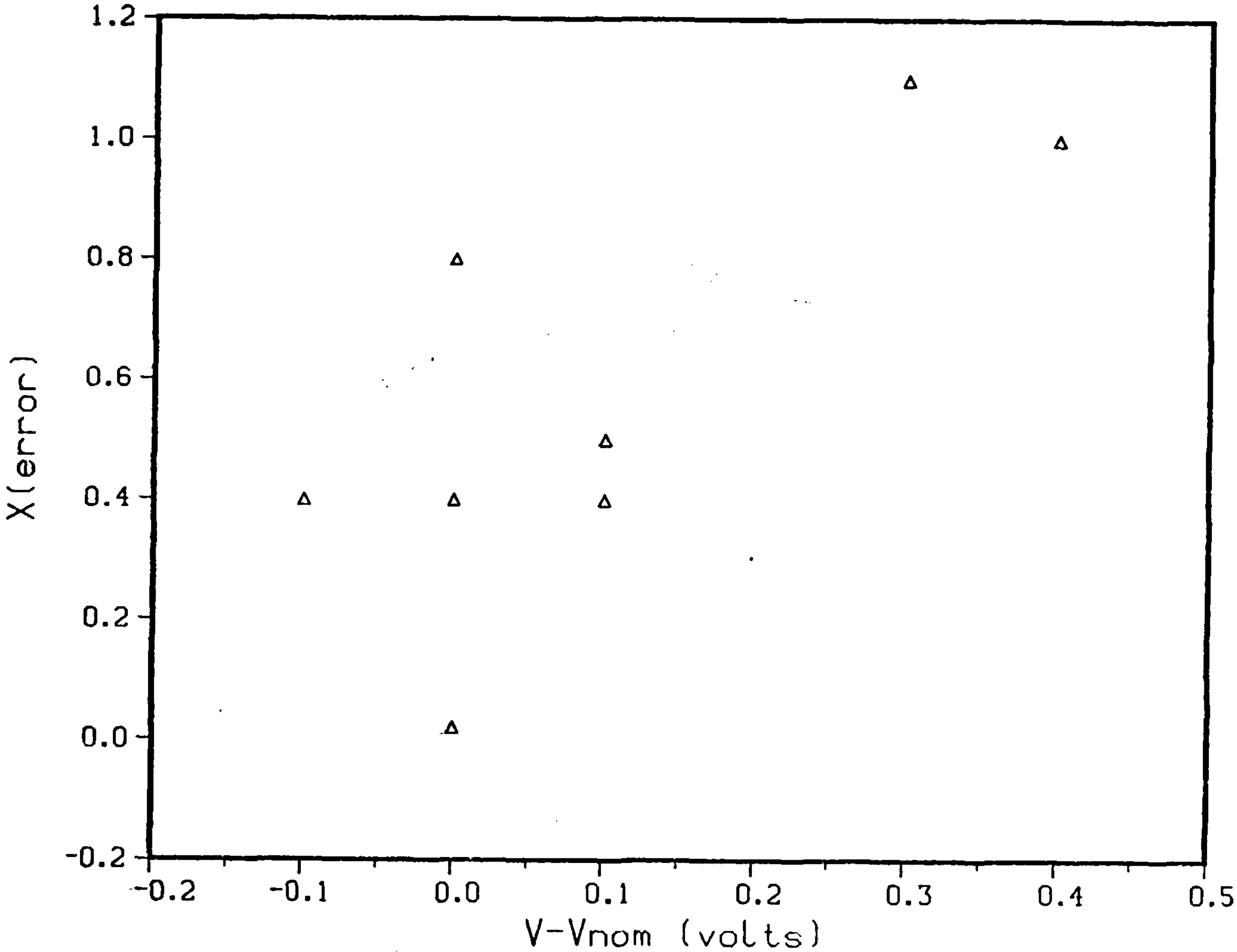


Figure 3.7

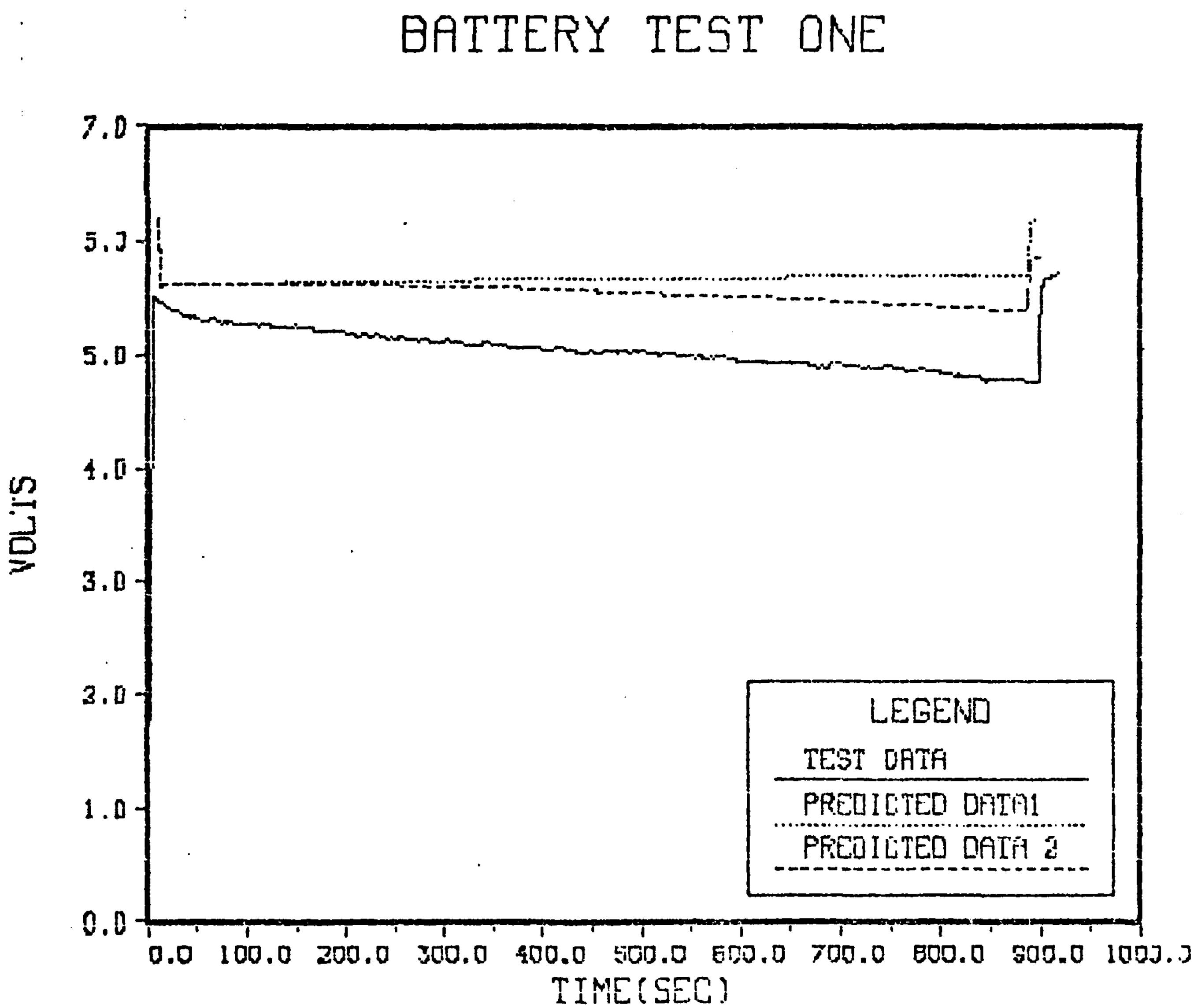


Figure 3.8 Constant Discharge Rate

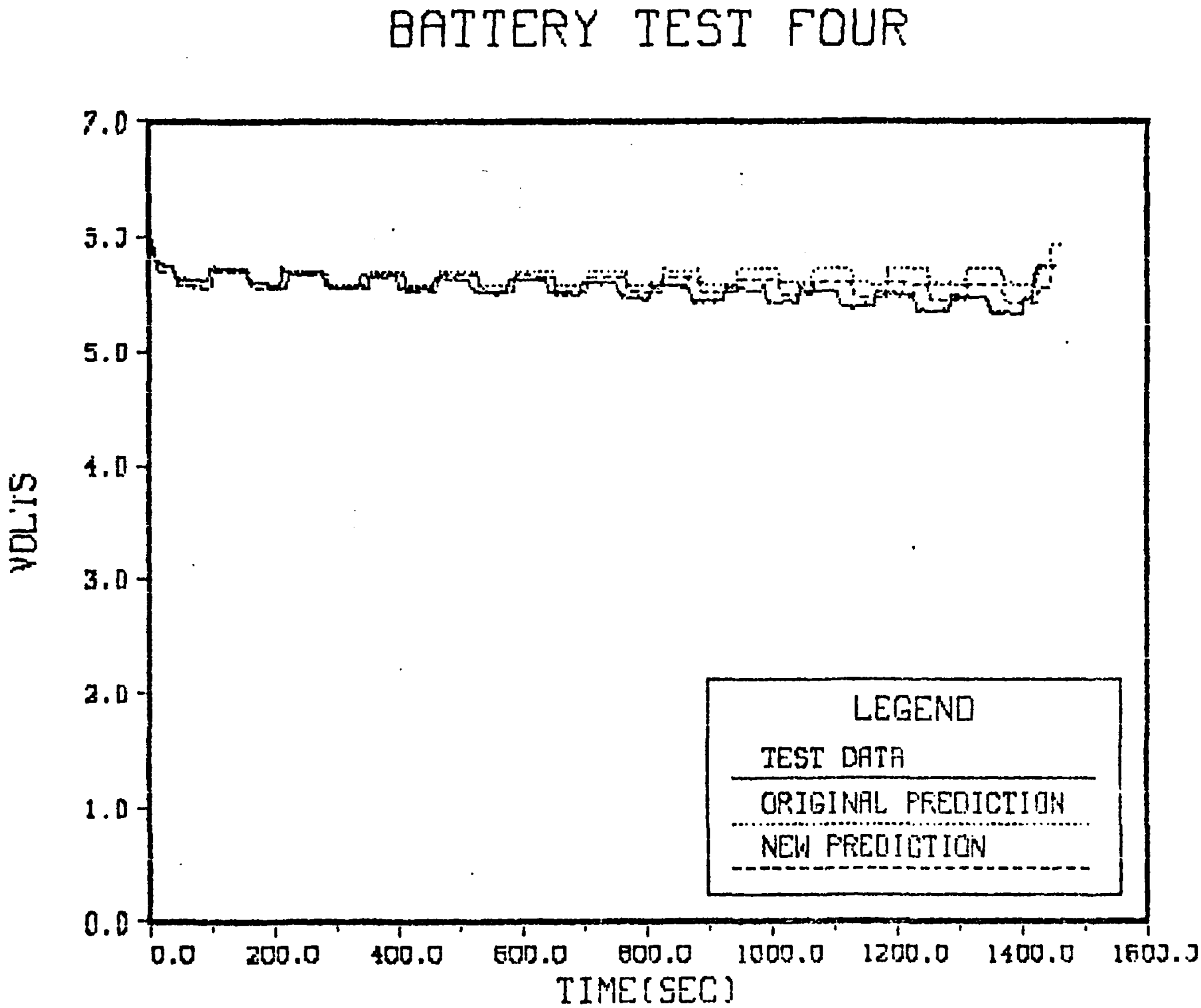


Figure 3.9 Varying Discharge Rate

TABLE II

Average Difference

(Experimental vs. Simulation)

Test No.	ΔV	σ	No. of Samples
1	.5	.1	239
2 a	1.0	.2	547
b	.02	.1	545
3	.4	.1	1016
6	.4	.1	319
7	.4	.1	210
8 a	1.1	.1	882
b	.8	.1	882

For tests 2 and 8, results a include the errors caused by the initial battery overcharge while results b have these errors removed.

IV. Hybrid Simulation

While a simple model for an internal combustion engine was included in the original version of EVSIM, a more accurate and versatile model was needed to predict the performance of a hybrid vehicle in HVSIM.

Objectives

The first objective was to develop a model that could predict both the available power and the fuel consumption of the internal combustion engine. The model had to be versatile enough to cover both spark ignition and compression ignition engines.

The second objective was to test the internal combustion engine selected for the test vehicle and compare the results of the tests to the predictions of the model.

Internal Combustion Engine Model

The key to this model is the assumption that the full throttle torque curve can be represented by a second degree equation of the form:

$$T = a + bN + cN^2 \qquad (3)$$

where T is torque and N is engine rpm. This assumption is reasonable in the normal operating region of most engines (Ref 3). This method can be used for both spark ignition and combustion ignition engines, although their torque curves are different (fig.4.1,4.2). Spark ignition engines a, b, and c are found knowing $dT/dN = 0$ at N_2, $T_1 = T_{bhpmax}$ at N_1, and $T_2 = T_{max}$ at N_2.

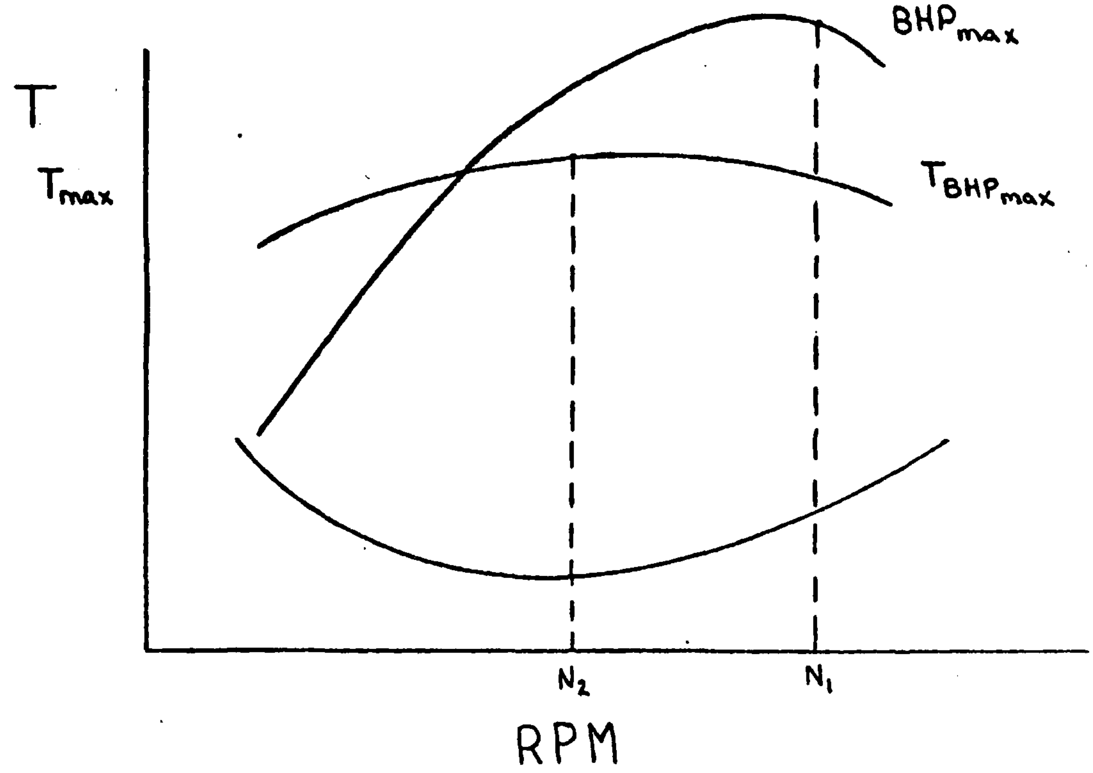


Figure 4.1 SI Engine

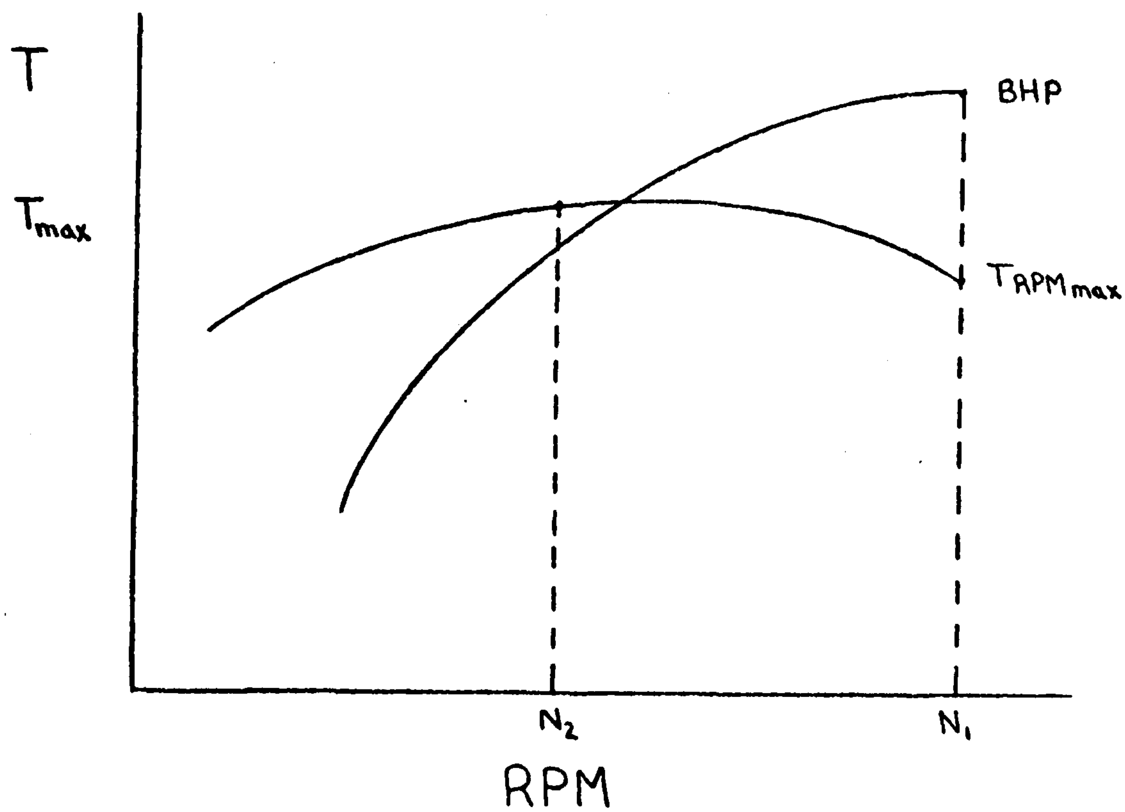


Figure 4.2 CI Engine

For combustion ignition engines, equation 3 can be solved knowing $dT/dN = 0$ at N_2, $T_2 = T_{max}$ at N_2, and $T_1 = T_{maxrpm}$ at N_1. Using these boundary conditions to solve equation 3 yields

$$c = (T_1 - T_2)/(N_2^2 - 2N_1N_2 + N_1^2) \quad (4)$$

$$b = -2cN_1 \quad (5)$$

$$a = T_2 + cN_2^2 \quad (6)$$

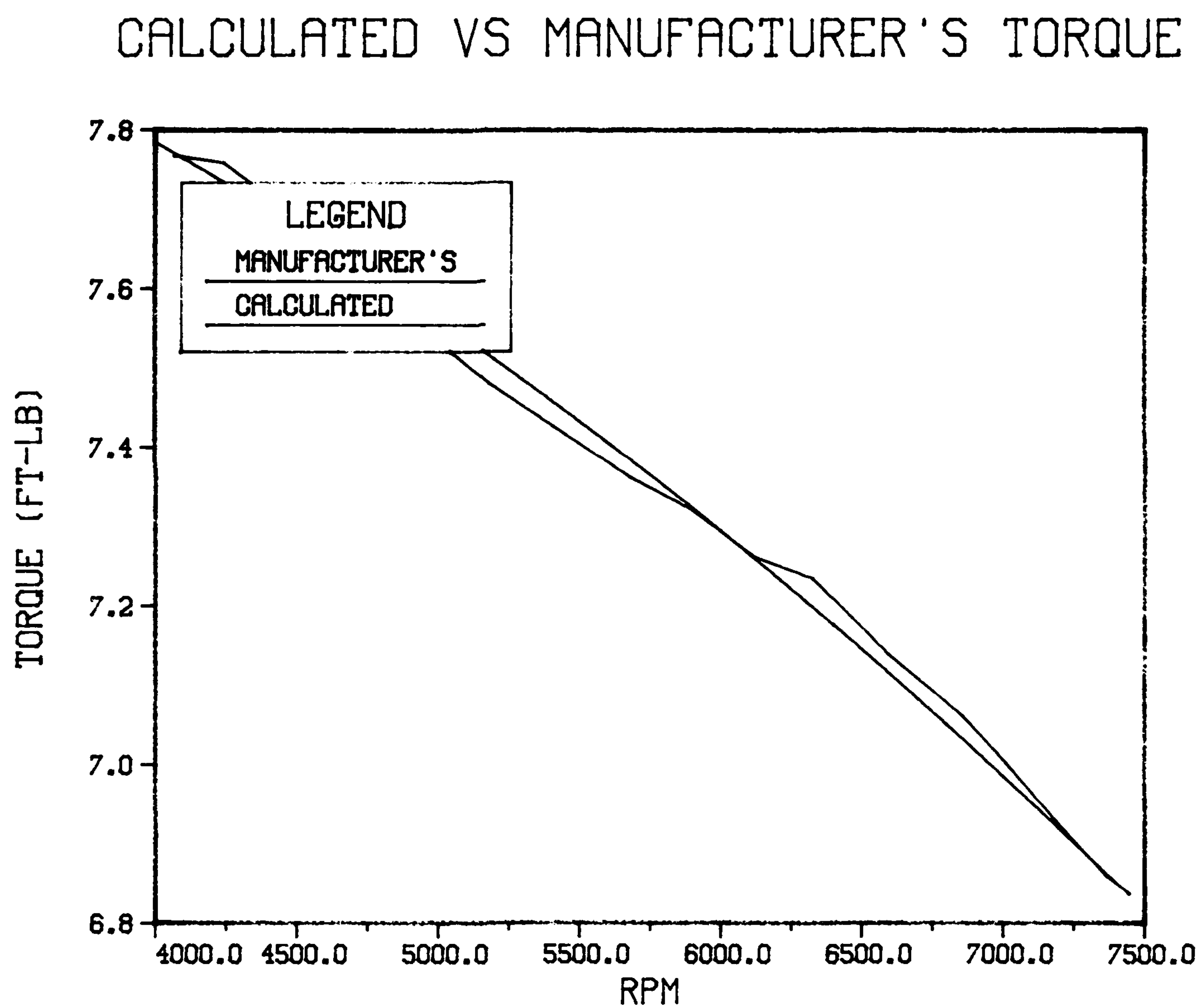
Having solved equation 3, the brake horsepower can be obtained from:

$$\frac{T \times N}{5252} \quad (7)$$

Figure 4.3 shows the torque calculated from equation 3 plotted with the torque curve supplied by the IC engine manufacturer. Figure 4.4 shows the BHP predicted by the engine model and the manufacturer's horsepower curve.

IC Engine Test

The engine used in the test vehicle was tested in accordance with SAE engine test code SAE J816b (Ref 20). The engine's torque was measured with a water brake dynamometer and its rpm with a stroboscope. The measured horsepower is plotted with the manufacturer's estimated horsepower in figure 4.5. The measured torque was used to make a new estimate of the engine's horsepower; this is plotted in figure 4.6.


CALCULATED VS MANUFACTURER'S TORQUE
LEGEND
MANUFACTURER'S
CALCULATED
TORQUE (FT-LB)
7.8
7.6
7.4
7.2
7.0
6.8
4000.0
4500.0
5000.0
5500.0
6000.0
6500.0
7000.0
7500.0
RPM
Figure 4.3

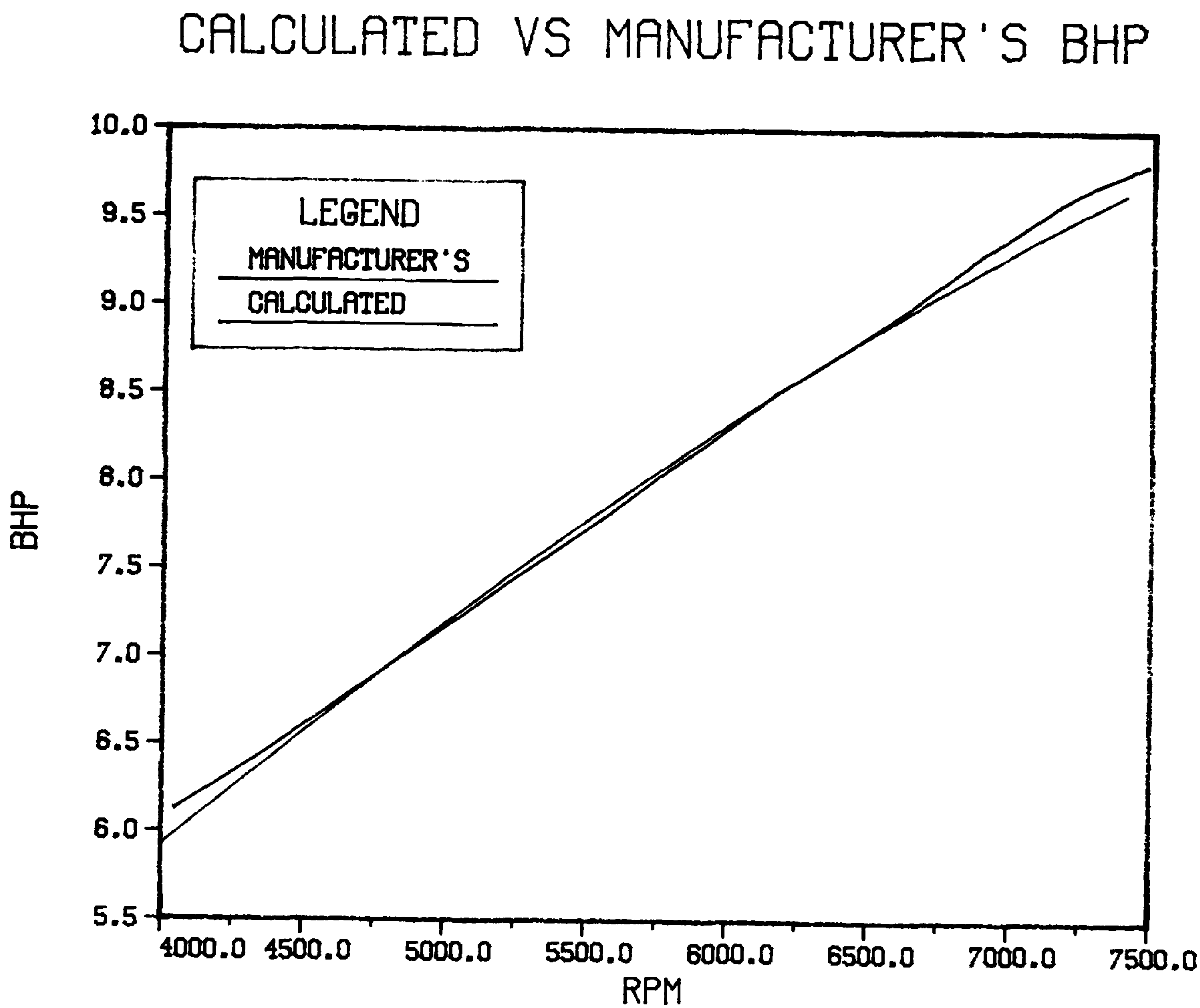
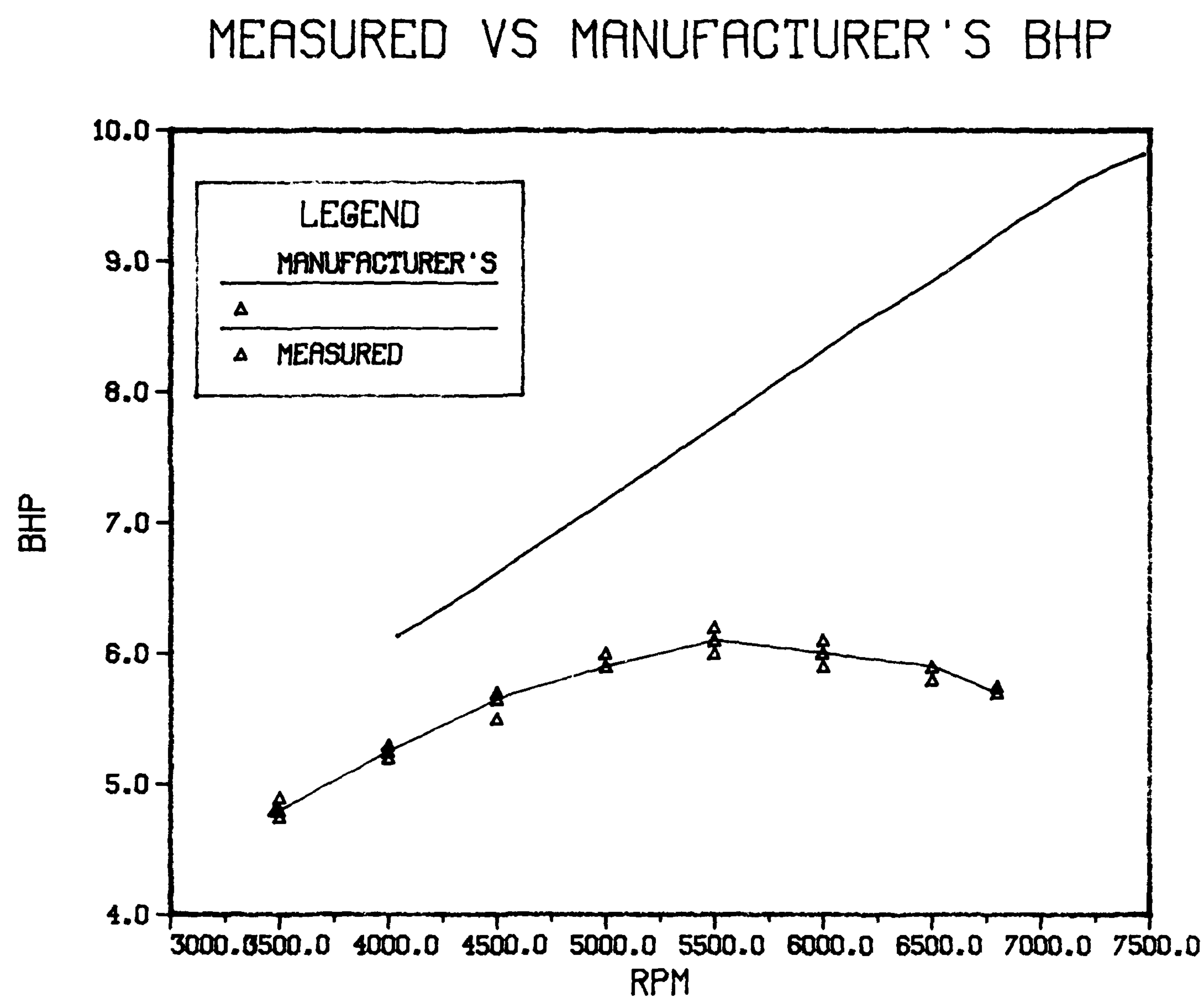

CALCULATED VS MANUFACTURER'S BHP
LEGEND
MANUFACTURER'S
CALCULATED
BHP
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
4000.0
4500.0
5000.0
5500.0
6000.0
6500.0
7000.0
7500.0
RPM

Figure 4.4


MEASURED VS MANUFACTURER'S BHP
LEGEND
MANUFACTURER'S
MEASURED
BHP
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
6000.0
6500.0
7000.0
7500.0
RPM
Figure 4.5

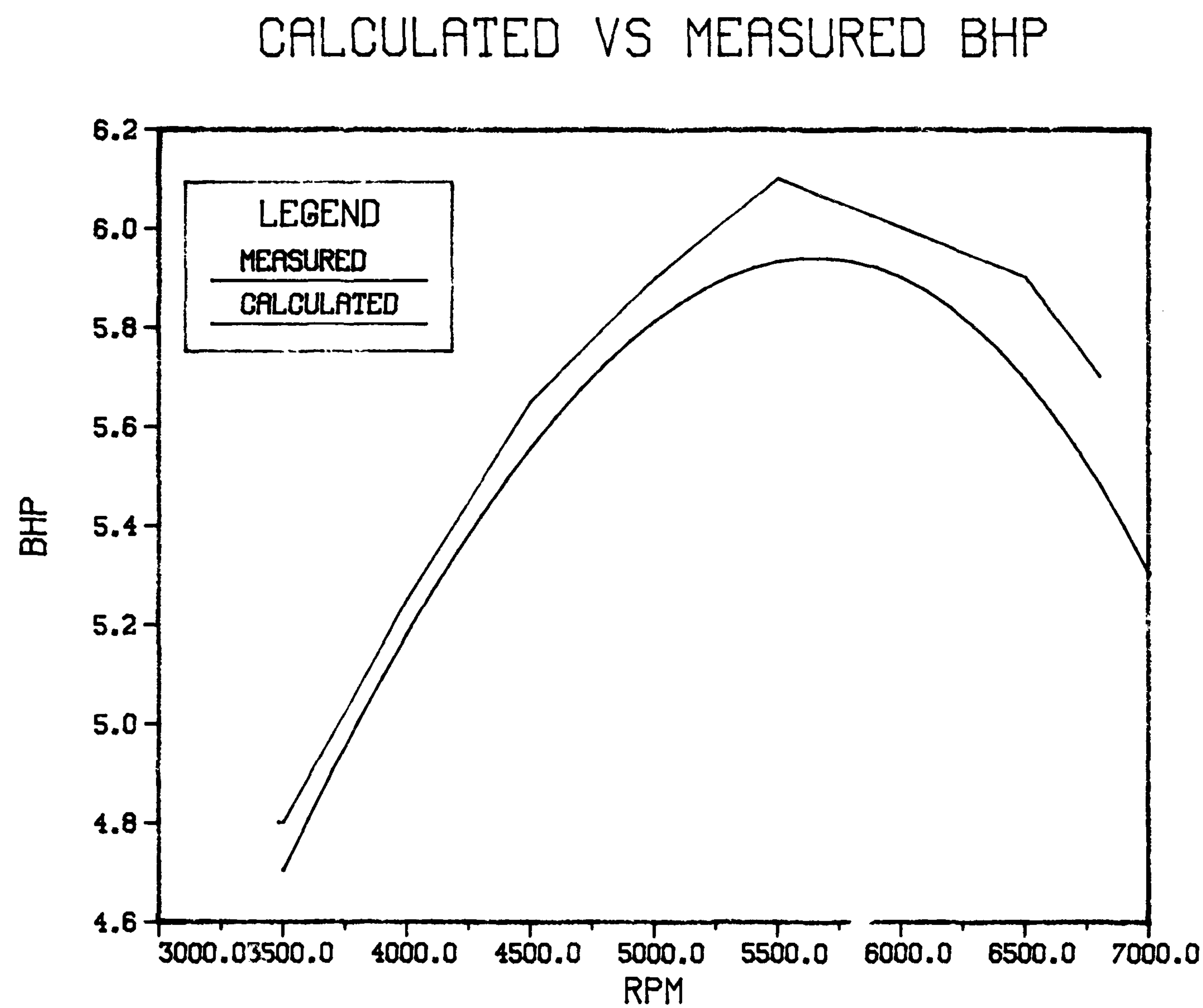

CALCULATED VS MEASURED BHP
LEGEND
MEASURED
CALCULATED
BHP
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
6000.0
6500.0
7000.0
RPM

Figure 4.6

Conclusions

1. The results in figure 4.3 and 4.4 shows the importance of testing the engine in the configuration it will be used in. The manufacturer's horsepower curve was based on an engine with no muffling. The engine was tested with the exhaust pipe and muffler used in the test vehicle.

2. The IC engine model is accurate to within several percent over the range of interest for full throttle operations.

V. Hybrid Vehicle Test and Simulation

In this chapter the results of complete vehicle simulation are compared to the measured performance of the test vehicle. The simulation results and the test vehicle performance will be compared for hybrid and all electric configurations.

Vehicle Simulation

The program HVSIM was run using both the general battery model and the model developed specifically for the batteries used in the test vehicle both of these models use the change recommended in chapter three. By comparing the results of these simulations the effect of the battery model's accuracy on the overall simulation accuracy could be determined. The driving cycle used was the test vehicle's speed schedule.

Vehicle Test

The vehicle was driven around a 5.2 mile course. The test course contained approximately 2.5 miles of hills up to a 10% grade. The speed and electric energy used were recorded. The vehicle was driven around the course first with the IC engine operating and then with only the electric engine. Table III shows the speed schedule of the test vehicle for both the hybrid and electric tests.

Vehicle Test and Simulation Results

Table IV shows the results of the all electric test and simulation. The first simulation used the general battery model developed in Chapter 3. The second simulation uses the battery model developed specifically for the

Table III

Vehicle Speed Schedule

Time (minutes)	(sec)	Distance (miles)	Speed (mph)
	51	.5	35
2	12	1.4	40
3	02	2.0	43
4	03	2.6	35
4	54	3.1	35
6	15	4.0	40
7	05	4.6	43
8	07	5.2	35

Table IV

Electric Test and Simulation Results

	Test Vehicle	HVSIM	Experimental Battery Model
Time (min):	8.1	8.1	8.1
Distance (km):	8.4	8.2	8.2
Energy used (kw-hr) Electric Energy:	1.06	.8	.8

Table V

Hybrid Test and Simulation Results

	Test Vehicle	HVISM
Time (min):	8.1	8.1
Distance (km):	8.4	8.2
Energy used (kw-hr)		
Electric Energy:	.65	.46
IC Engine:	.41	.33
Total Energy:	1.06	.79

batteries used in the test vehicle. Table V shows the results of the hybrid test and simulation.

Conclusions

1. The difference in the accuracy of the battery models used had very little effect on the overall accuracy of the vehicle simulation.

2. The hybrid simulation can accurately predict the relative amount of energy supplied by the electric motor and the IC engine.

3. The simulation doesn't take hills into account in its prediction of vehicle performance. This accounts for most of the underprediction of the energy used by the test vehicle.

Recommendations

1. A more accurate evaluation of HVSIM would require further testing of the vehicle on a flat test track and added instrumentation to measure the fuel flow to the engine.

2. The energy supplied by the IC engine could be increased if the pulley size was adjusted to allow it to operate at more efficent speeds.

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APPENDIX A

Battery Testing

The batteries were tested under the following eight different combinations of temperature and discharge rate:

Test 1: 21^{o} C, 158 amps constant discharge for 15 minutes.

Test 2: 21^{o} C, 93 amps constant discharge for 30 minutes.

Test 3: 26^{o} C, 44 amps constant discharge for one hour with a six hour rest and a second discharge for 17 minutes.

Test 4: 26^{o} C, varying discharge between 46 and 75 amps for 24 minutes.

Test 5: 6^{o} C, 40 amps constant discharge for 40 minutes.

Test 6: 5^{o} C, 90 amps constant discharge for 20 minutes.

Test 7: 7^{o} C, varying discharge between 103 and 132 amps for 13 minutes.

Test 8: 5^{o} C, 67 constant discharge for 49 minutes.

Figures A1 through A8 are the results of these tests.

Figure A.9 shows the test setup used in the discharge experiments. The batteries were discharged through a 4 inch by 4 inch bar of graphite 3 feet long. Terminal posts were placed along the length of the bar. By changing the terminals the battery was connected to the discharge rate of the battery was adjusted. The terminal voltage and the current flowing through the rod were recorded on a strip chart recorder. The data was transferred to a VAX 11/780 with an HP digitizer for processing.

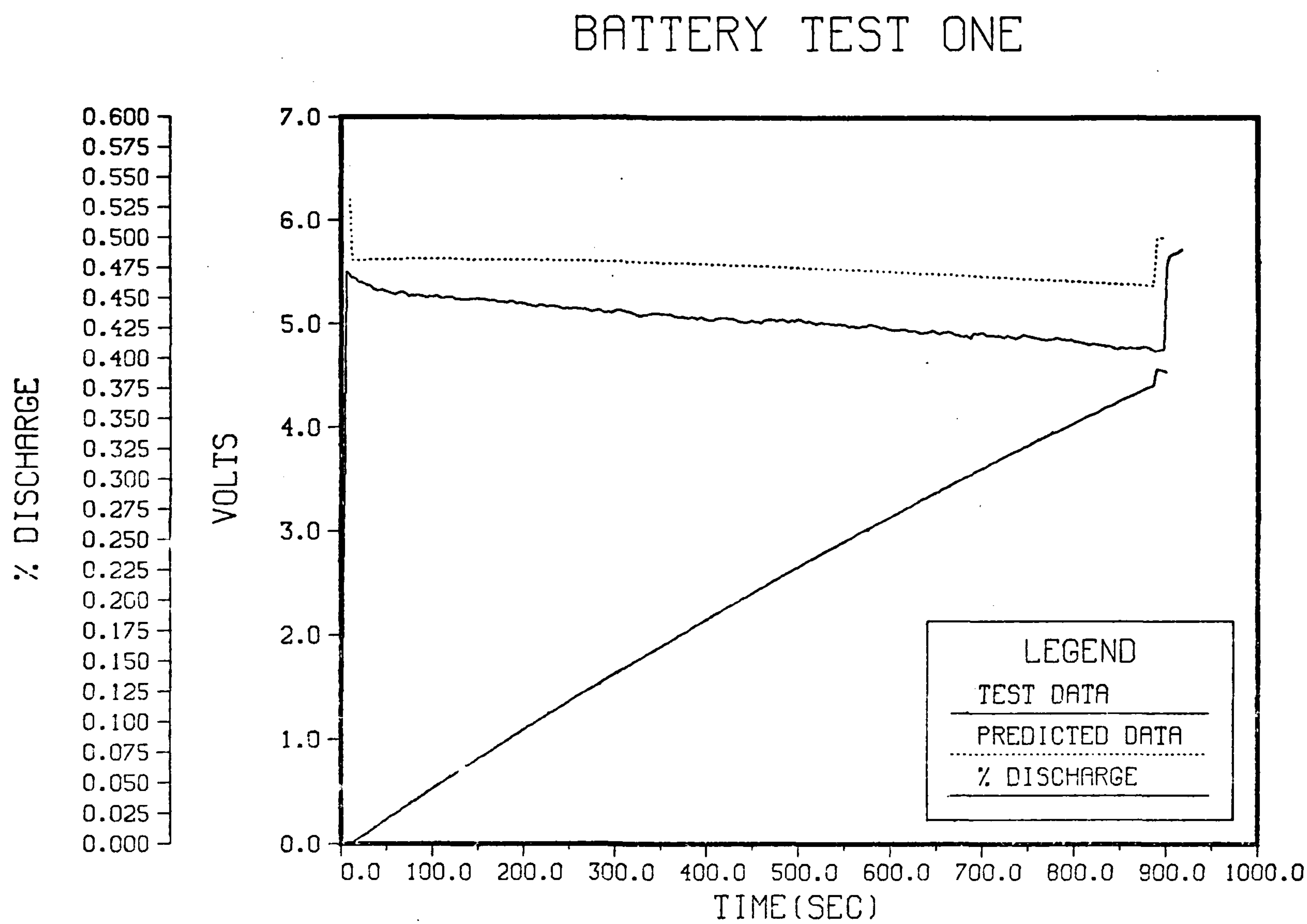

BATTERY TEST ONE
% DISCHARGE
0.600
0.575
0.550
0.525
0.500
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
VOLTS
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
TIME(SEC)
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE

Figure A.1

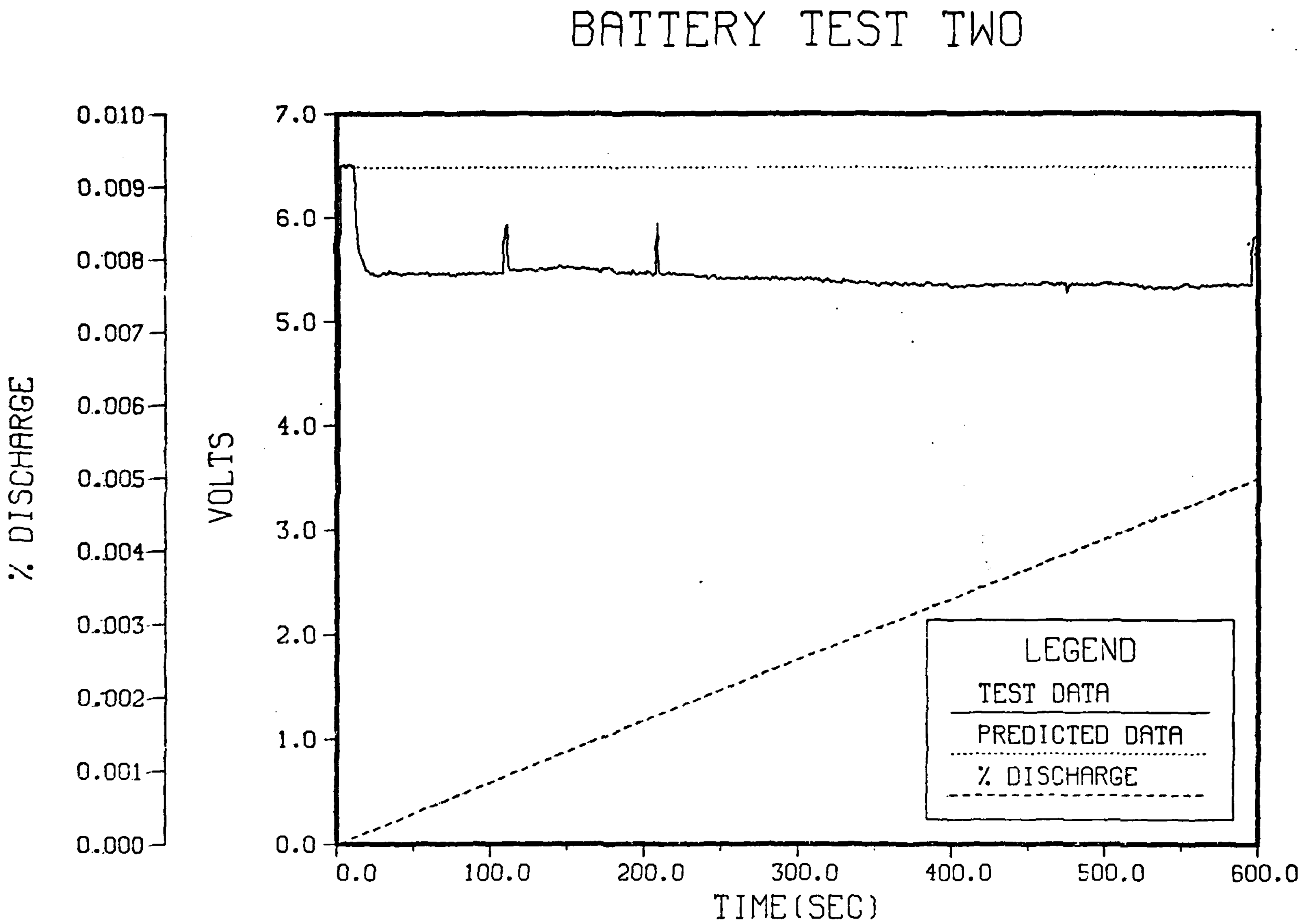

BATTERY TEST TWO
% DISCHARGE
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
VOLTS
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
TIME(SEC)
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE

Figure A.2

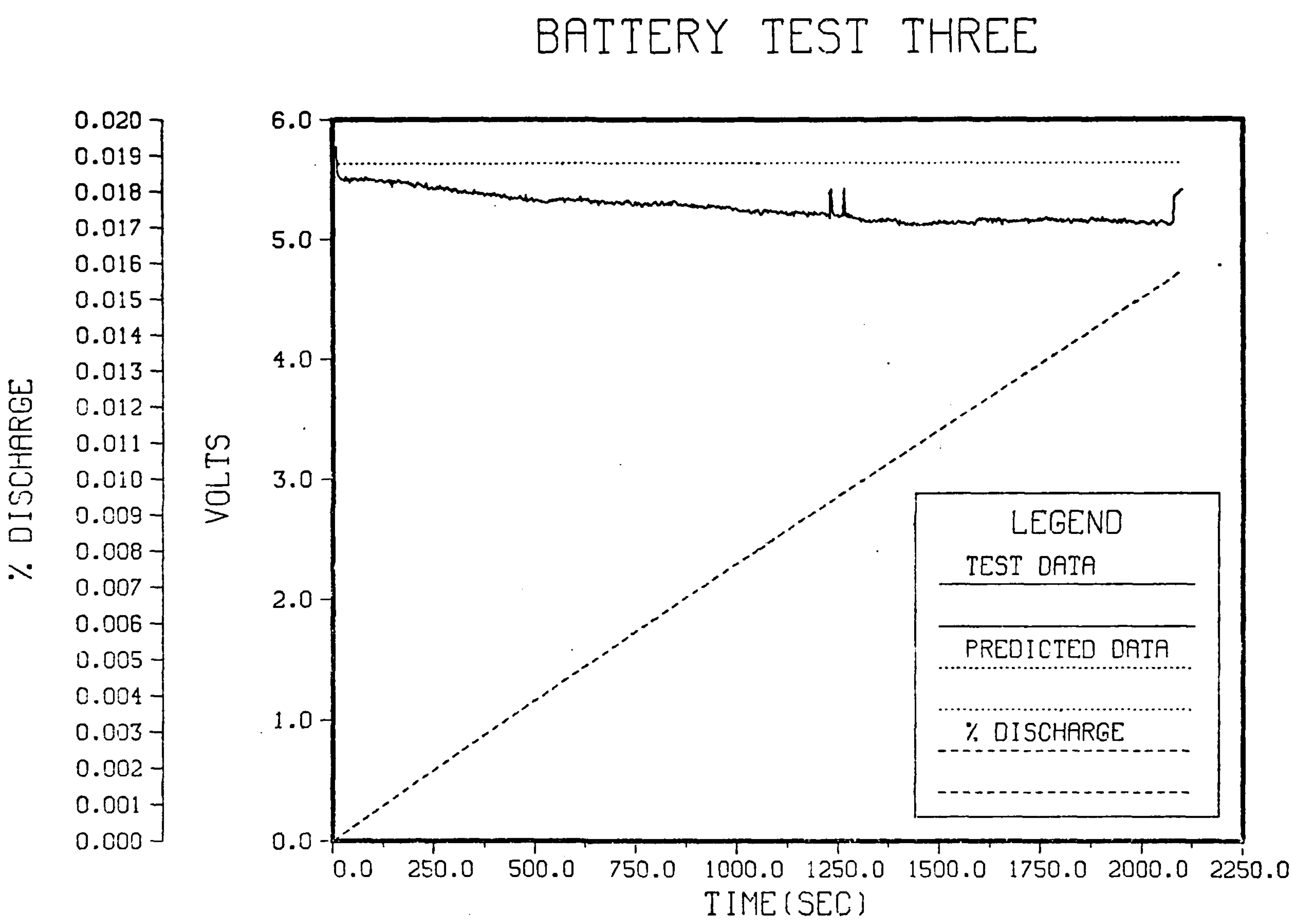

BATTERY TEST THREE
% DISCHARGE
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
VOLTS
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
250.0
500.0
750.0
1000.0
1250.0
1500.0
1750.0
2000.0
2250.0
TIME(SEC)
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE

Figure A.3

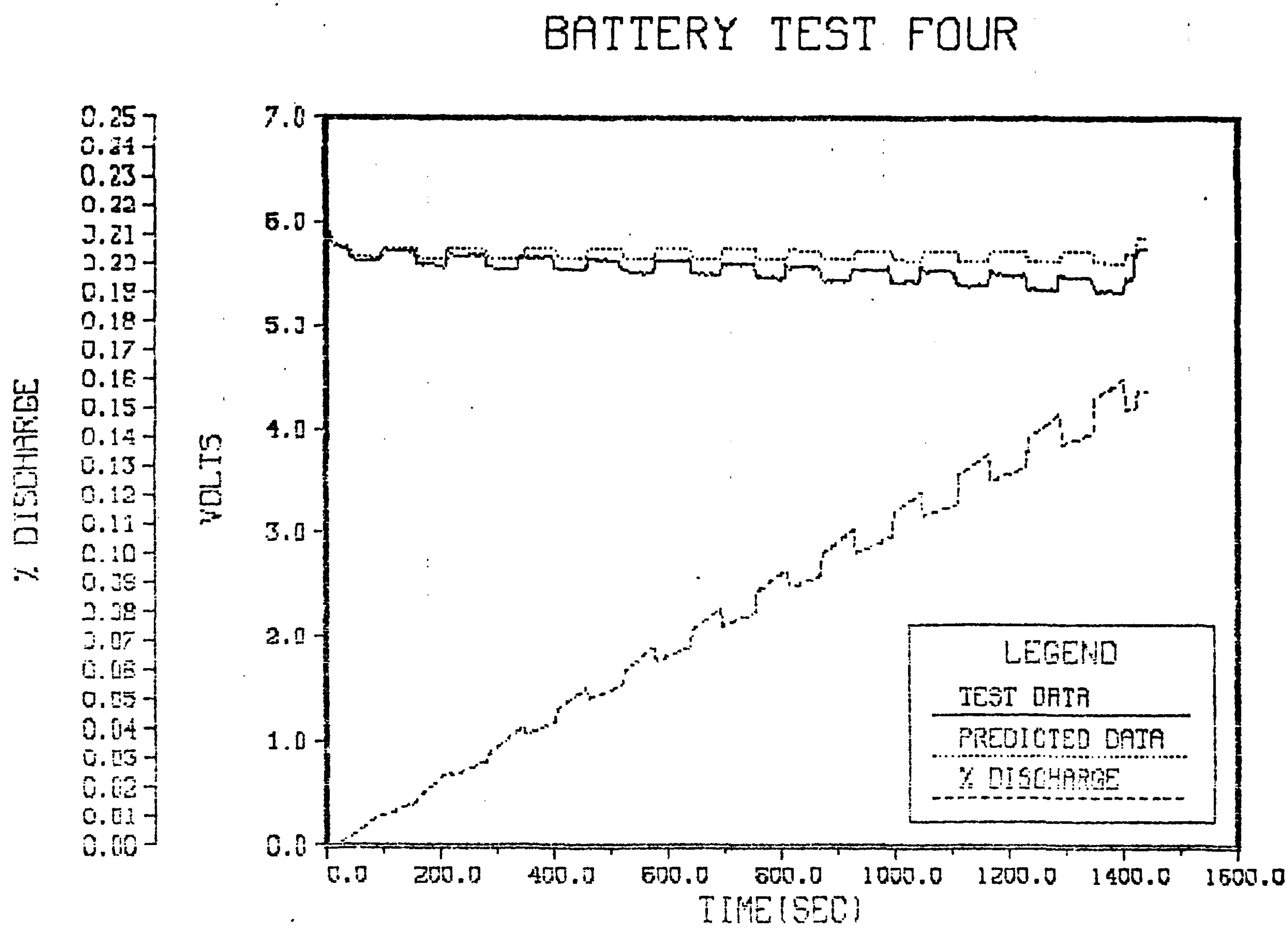

BATTERY TEST FOUR
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE
% DISCHARGE
VOLTS
TIME(SEC)
0.00
0.05
0.10
0.15
0.20
0.25
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0

Figure A.4

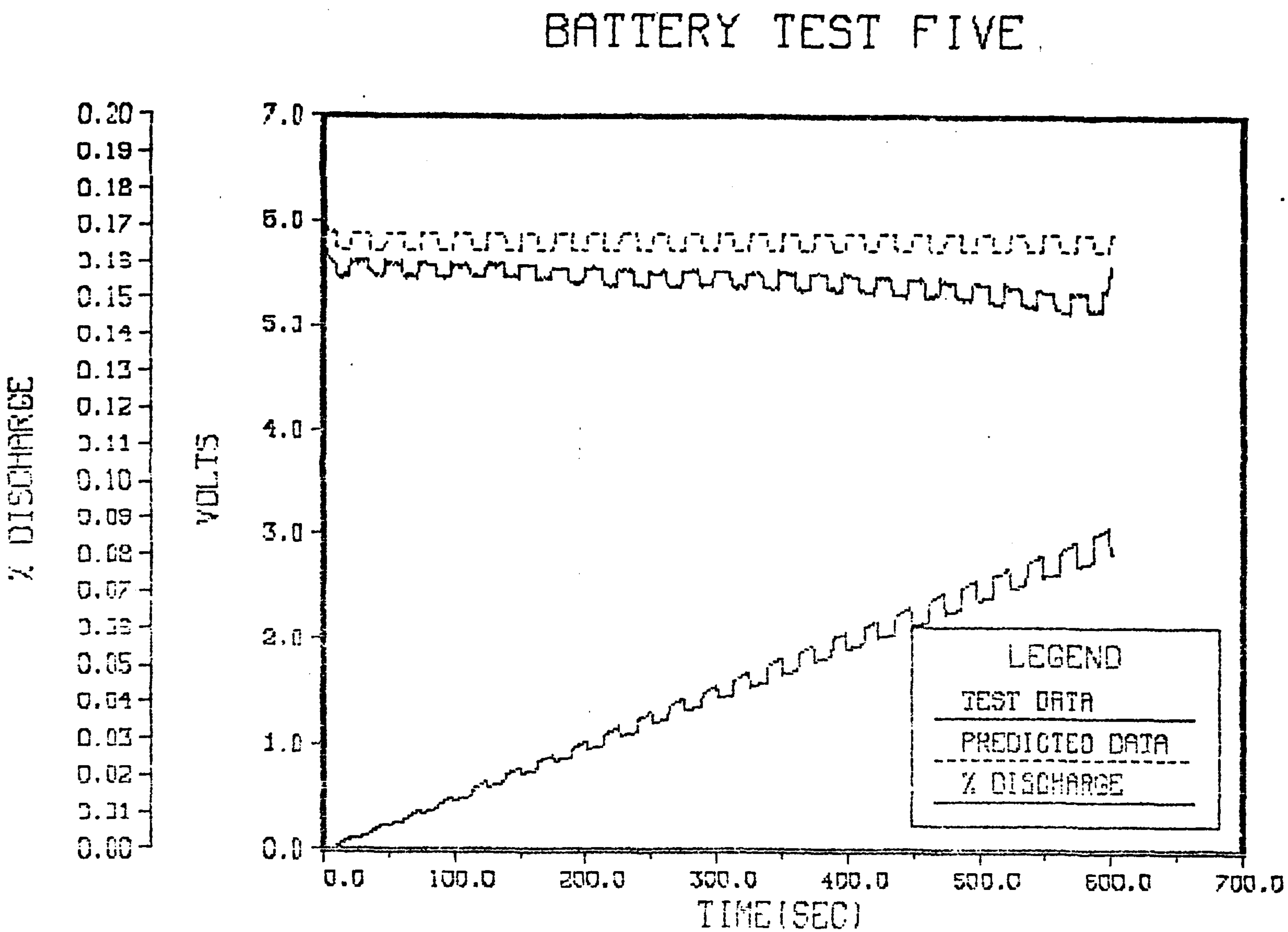
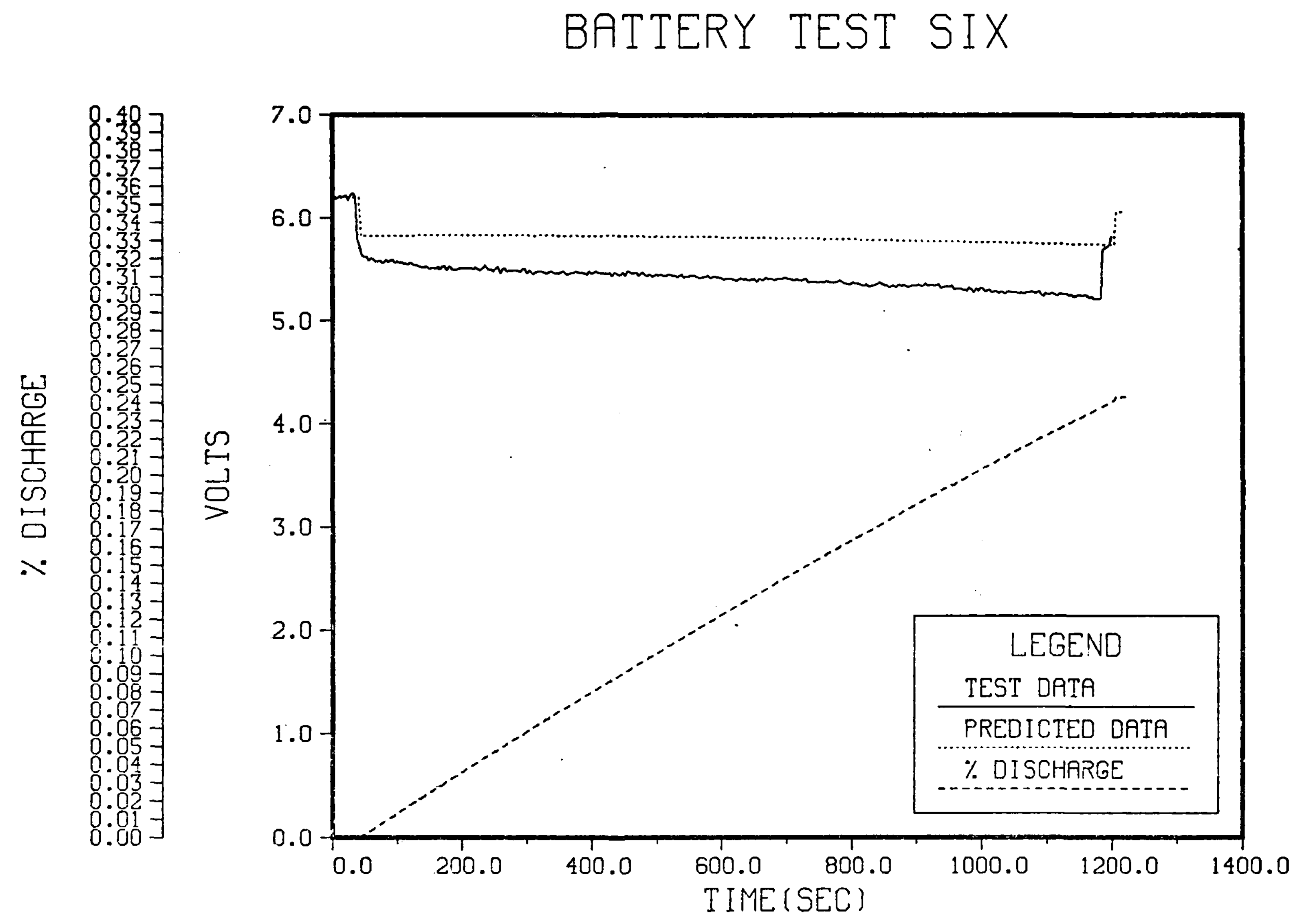

BATTERY TEST FIVE
% DISCHARGE
VOLTS
TIME(SEC)
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE

Figure A.5



BATTERY TEST SIX
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE
VOLTS
% DISCHARGE
TIME(SEC)
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.21
0.22
0.23
0.24
0.25
0.26
0.27
0.28
0.29
0.30
0.31
0.32
0.33
0.34
0.35
0.36
0.37
0.38
0.39
0.40

Figure A.6

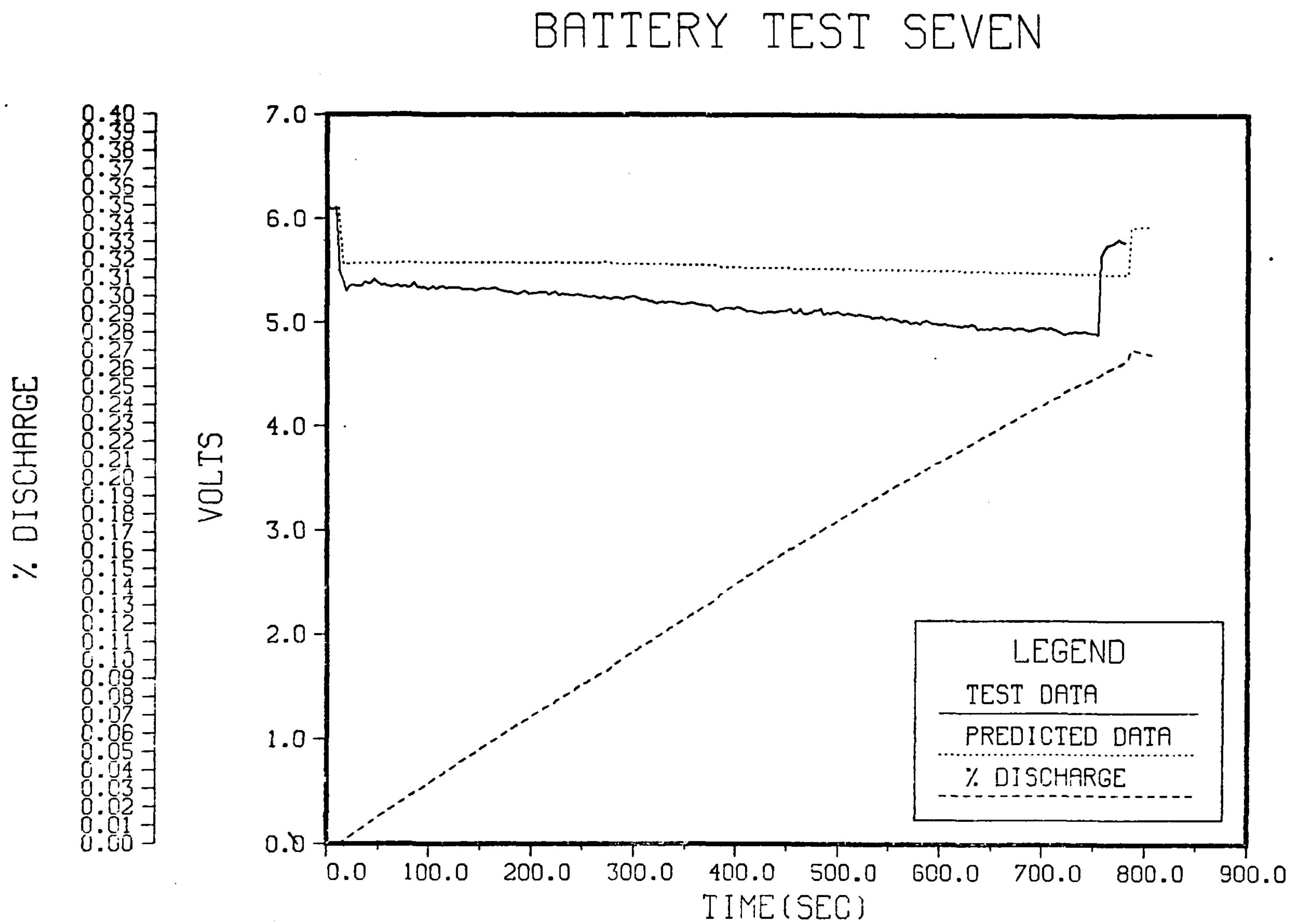

BATTERY TEST SEVEN
% DISCHARGE
0.40
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
VOLTS
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
TIME(SEC)
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE

Figure A.7

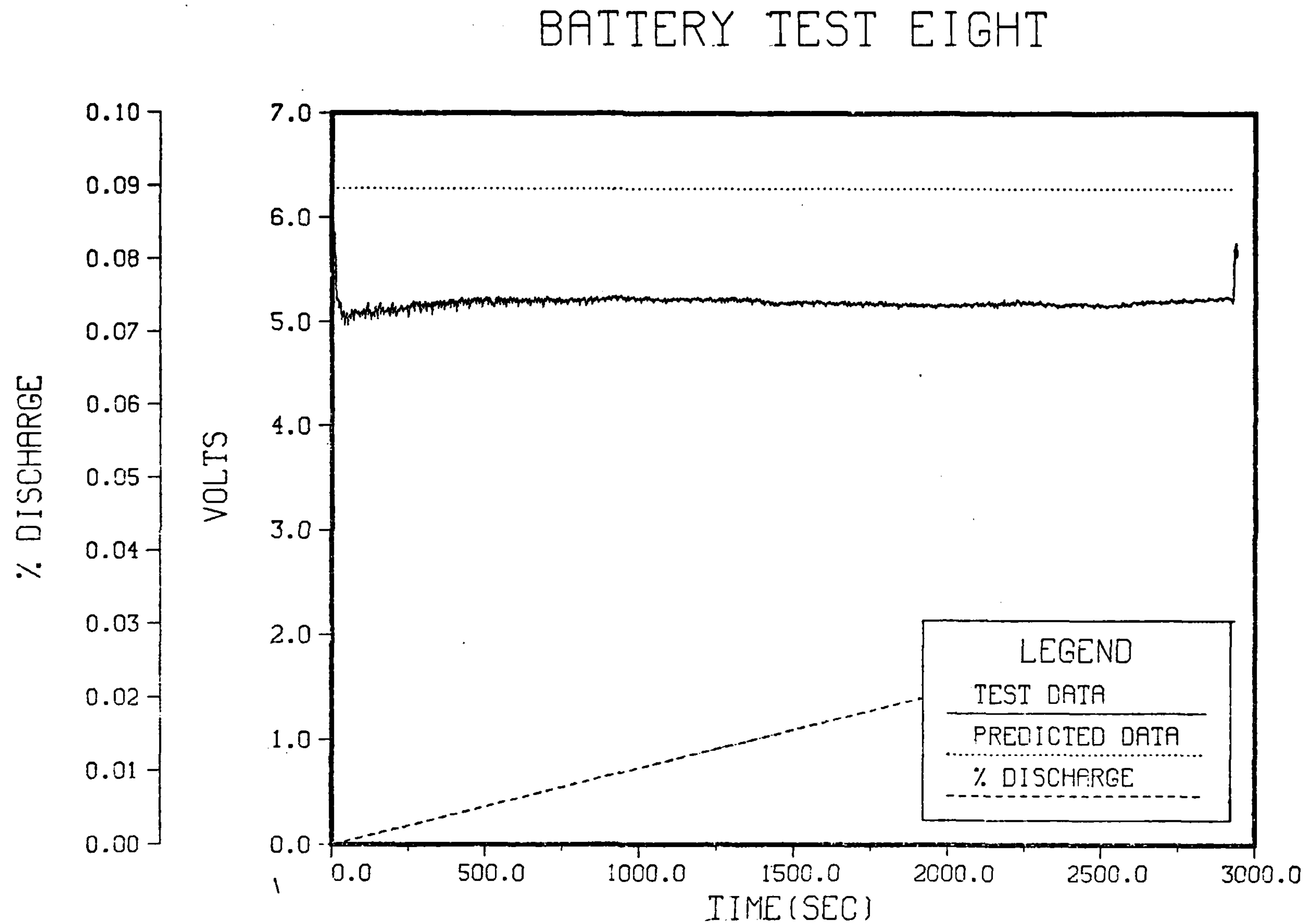

BATTERY TEST EIGHT
% DISCHARGE
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
VOLTS
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
TIME(SEC)
LEGEND
TEST DATA
PREDICTED DATA
% DISCHARGE

Figure A.8

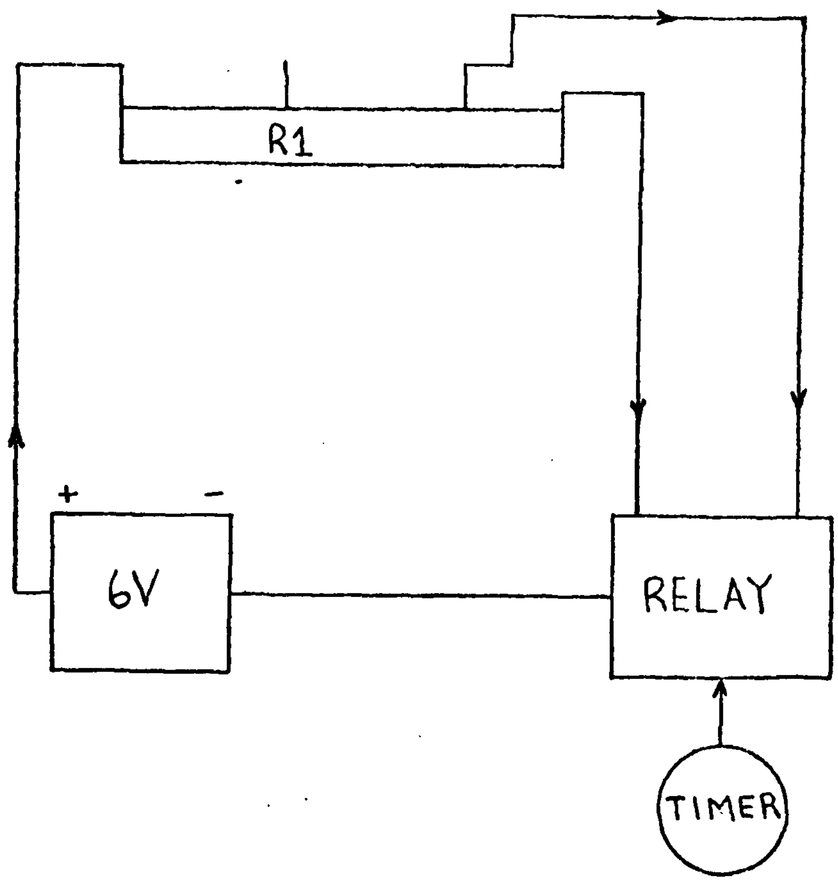


Figure A.9 Test Configuration

APPENDIX B

HVSIM

This appendix is a listing of HVSIM with the major changes from EVSIM marked with an * and a sample of its output.

```
C     PROGRAM EVSIM(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION VX(14ØØ),GR(1Ø),CSTP(5),MSTP(1Ø),ETAM(1Ø,3Ø),ETAT(1Ø,2Ø)
     C,TSTP(1Ø),RBAT(5),RBAT1(5),V(14ØØ)
      REAL  MM,M,MS,KMOT,MSTP,M1,MCF,MSH
      OPEN (UNIT=1,FILE='EVS.DAT',STATUS='OLD',READONLY)
      OPEN (UNIT=5,FILE='CARTEST.DAT',STATUS='OLD',READONLY)
 9ØØ  FORMAT(1ØF5.1)
 9Ø1  FORMAT(18F4.1)
      WRITE(6,9Ø2)
 9Ø2  FORMAT(1H1,31X67H' ' 'E L E C T R I C   V E H I C L E   S I M U
     CL A T I O N ' ' ')
C
C     ENTER VEHICLE CONSTANTS. DRAG COEFF(CD),FRONTAL AREA(FA), PAYLOAD
C     MASS(PM), FIXED MASS(FM).
C
      READ(1,*)CD,FA,PM,FM
      WRITE(6,9Ø3)
 9Ø3  FORMAT(///2ØX22HVEHICLE CONSTANTS ARE:)
      WRITE(6,9Ø4)CD,FA,PM,FM
 9Ø4  FORMAT(35X17HDRAG COEFFICIENT=,F5.2,/35X13HFRONTAL AREA=,F5.2,14H
     CSQUARE METERS,/35X13HPAYLOAD MASS=,F4.Ø,1ØH KILOGRAMS,/35X11HFIXED
     C MASS=,F4.Ø)
C
C     ENTER ENVIRONMENTAL CONSTANTS. AMBIENT TEMPERATURE(TMP), ELECTRIC
C     POWER COST(ECOST), PETROLEUM FUEL COST(FCOST).
C
      READ(1,*)TMP,ECOST,FCOST
      WRITE(6,9Ø5)
 9Ø5  FORMAT(/2ØX28HENVIRONMENTAL CONSTANTS ARE:)
      WRITE(6,9Ø6)TMP,ECOST,FCOST
 9Ø6  FORMAT(35X2ØHAMBIENT TEMPERATURE=,F4.Ø,8H CELSIUS,/35X23HELECTRIC
     CENERGY COST= $,F4.3,9H PER KWHR,/35X22HPETROLEUM FUEL COST= $,F4.2
     C,1ØH PER LITER)
C
C     ENTER VEHICLE POWER REDUCTION VARIABLES. ROLLING RADIUS(RR), TIRE
C     ROLLING COEFFICIENT(CR), AXLE RATIO(AR), NUMBER OF FORWARD SPEEDS
C     )Ø IF CVT (IS), MAX VEHICLE DESIGN SPEED(VMAX).
C
      READ(1,*)RR,CR,AR,IS,VMAX
      WRITE(6,9Ø7)
 9Ø7  FORMAT(/2ØX3ØHPOWER REDUCTION VARIABLES ARE:)
      WRITE(6,9Ø8)RR,CR,AR,IS,VMAX
 9Ø8  FORMAT(35X2ØHTIRE ROLLING RADIUS=,F6.3,7H METERS,/35X2ØHROLLING CO
     CEFFICIENT=,F7.4,/35X11HAXLE RATIO=,F5.2,/35X21HNUMBER FORWARD GEAR
     CS=,I2,/35X17HMAXIMUM VELOCITY=,F4.Ø,6H KM/HR)
      IF(IS.EQ.Ø)GO TO 2Ø
 1Ø   CONTINUE
C
```

```
C     ENTER TRANSMISSION RATIOS)IF MULTISPEED (GR(IS)) ON FIRST CARD. ON
C     NEXT CARD ENTER DESIRED MOTOR UPSHIFT AND DOWNSHIFT RPM(UPSHFT,
C     DNSHFT).
C
      READ(1,*)(GR(I),I=1,IS)
      READ(1,*)UPSHFT,DNSHFT
      WRITE(6,909)
  909 FORMAT(/20X39HFIXED SPEED TRANSMISSION VARIABLES ARE:)
      WRITE(6,910)UPSHFT,DNSHFT,GR(1)
  910 FORMAT(35X20HMOTOR UPSHIFT SPEED=,F5.0,4H RPM,/35X22HMOTOR DOWNSHI
     CFT SPEED=,F5.0,4H RPM,/35X12HGEAR RATIOS=,F6.3)
      IF (IS.EQ.1)GO TO 30
   11 DO 12 I=2,IS
   12 WRITE(6,911)GR(I)
  911 FORMAT(47X,F6.3)
      GO TO 30
   20 CONTINUE
C
C     ENTER CVT VARIABLES. RATED INPUT POWER(PRATT) AND NUMBER OF SPEED
C     RATIO STEPS FOR INPUT DATA ON FIRST CARD, EFFICIENCY DATA(ETAT)
C     ON NEXT CARD SERIES: FIRST CARD- SPEED RATIO STEPS(TSTP), FOL-
C     LOWING CARDS- ETAT).GT.0 AND .LT.1  IN 10F5.1 FOR EACH 5( OF PRATT
C     FROM 5( TO100(. 2 CARDS REQD FOR EACH TSTP .
C
      READ(1,*)PRATT,ITSTP
      READ(1,*)(TSTP(I),I=1,ITSTP)
      DO 21 I=1,ITSTP
      DO 21 J=1,2
   21 READ(1,900)(ETAT(I,(J-1)*10+K),K=1,10)
      WRITE(6,912)
  912 FORMAT(/20X49HCONTINUOUSLY VARIABLE TRANSMISSION VARIABLES ARE:)
      WRITE(6,913)PRATT
  913 FORMAT(35X13HPOWER RATING=,F5.1,3H KW)
   30 CONTINUE
C
C     ENTER MOTOR VARIABLES. MOTOR TYPE(MTYP))0=SHUNT,1=SERIES , K FAC-
C     TOR(KMOT), ARMATURE RESISTANCE(RARM), FIELD RESISTANCE(RFLD),
C     RATED POWER(PRATM), MAX POW MULT(IPMAX), MAX CUR(AMAX), BASE SPEED
C     (BSPD), AND NUMBER OF SPEED STEPS FOR INPUT DATA ON FIRST CARD.
C     ENTER EFFICIENCY(ETAM) ON NEXT CARD SERIES: FIRST CARD- MOTOR
C     SPEED       STEP )RPM (MSTP), FOLLOWING CARDS- ETAM).GT.0 AND
C     .LT.1  IN 10F5.1 FOR EACH 10( OF PRATM UP TO 300()3 CARDS REQD
C     FOR EACH MSTP .
C
      READ(1,*)MTYP,KMOT,RARM,RFLD,PRATM,IPMAX,AMAX,BSPD,IMSTP
      READ(1,*)(MSTP(I),I=1,IMSTP)
      DO 31 I=1,IMSTP
      DO 31 J=1,3
   31 READ(1,900)(ETAM(I,(J-1)*10+K),K=1,10)
      WRITE(6,914)
  914 FORMAT(/20X20HMOTOR VARIABLES ARE:)
      IF(MTYP.NE.0)GO TO 33
   32 CONTINUE
      WRITE(6,915)
  915 FORMAT(35X17HMOTOR TYPE= SHUNT)
```

```
      GO TO 34
 33   WRITE(6,916)
 916  FORMAT(35X18HMOTOR TYPE= SERIES)
 34   WRITE(6,917)PRATM,BSPD,AMAX
 917  FORMAT(35X12HRATED POWER=,F5.1,3H KW,/35X11HBASE SPEED=,F5.Ø,4H RP
     CM,/35X21HMAX ARMATURE CURRENT=,F5.Ø,5H AMPS)
 4Ø   CONTINUE
C
C     ENTER CONTROLLER VARIABLES. ENTER TYPE(CTYP) ON FIRST CARD: 1 IF
C     FINITE STEP SWITCHING, 2 IF CHOPPER.
C
      READ(1,*)CTYP
      IF(CTYP.NE.1.)GO TO 5Ø
 41   CONTINUE
C
C     ENTER FINITE STEP CONTROLLER VARIABLES, FIRST CARD- NUMBER OF VOLT
C     AGE STEPS(ICSTP). NEXT CARD- FRACTION OF FULL VOLTAGE FOR EACH
C     STEP(CSTP), AND EFFECTIVE SOURCE RESISTANCE(RBAT) FOR EACH STEP.
C
      READ(1,*)ICSTP
      READ(1,*)(CSTP(I),I=1,ICSTP),(RBAT(I),I=1,ICSTP)
      WRITE(6,92Ø)ICSTP,CSTP(1),RBAT(1)
      DO 42 I=2,ICSTP
 42   WRITE(6,921)CSTP(I),RBAT(I)
 92Ø  FORMAT(/2ØXI2,31H STEP CONTROLLER VARIABLES ARE:,/35X17HVOLTAGE FR
     CACTION=,F5.3,3X17HSOURCE IMPEDANCE=,F6.4,5H OHMS)
 921  FORMAT(52XF5.3,2ØXF5.3)
      GO TO 6Ø
 5Ø   CONTINUE
C
C     ENTER CHOPPER CONTROLLER SOURCE IMPEDANCE(RBAT). MODEL ASSUMES 1.5
C     VOLTS JUNCTION LOSS AND 3( RESISTIVE LOSS.
C
      READ(1,*)RBAT(1)
      WRITE(6,929)RBAT(1)
 929  FORMAT(/2ØX33HCHOPPER CONTROLLER VARIABLES ARE:,/35X17HSOURCE IMPE
     CDANCE=,F5.3,5H OHMS,/35X,32HASSUMED JUNCTION DROP= 1.5 VOLTS,/35X2
     C8HASSUMED RESISTIVE LOSSES= 3()
      CSTP(1)=1.
      ICSTP=1
 6Ø   DO 61 I=1,ICSTP
 61   RBAT1(I)=RBAT(I)
C
C     ENTER BATTERY VARIABLES. FIRST CARD- NOMINAL TOTAL VOLTAGE(VNOM)
C     AND TOTAL MASS(BM).
C
      READ(1,*)VNOM,BM
      BM1=BM
      WRITE(6,926)VNOM,BM
 926  FORMAT(/2ØX22HBATTERY VARIABLES ARE:,/35X,16HNOMINAL VOLTAGE=,F4.Ø
     C,/35X13HBATTERY MASS=,F5.Ø)
C
C     ENTER HYBRID VARIABLES. FIRST CARD- 1 IF HYBRID,Ø IF NOT. NEXT CAR
C     )IF IHYB=1 - HYBRID SPEED RATIO(HR), COUPLING EFFICIENCY(ETAH),
C     ENGAGEMENT SPEED(VH), NORMAL OPERATING TRANSMISSION GEAR(ISH),
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*C     MAX TORQUE(TOR1), TORQUE AT MAX RPM(TOR2), RPM AT MAX TORQUE(EN1)
*C     MAX RPM(EN2), FUEL FLOW AT MAX TORQUE(FF1), AND FUEL FLOW AT MAX
*C     RPM(FF2).
*C
*      READ(1,*)IHYB
*      HM=Ø.
*      VH=1ØØ.
*      IF(IHYB.EQ.Ø)GO TO 71
*      READ(1,*)HR,ETAH,VH,ISH,HM
*      READ(1,*)TOR1,TOR2,EN1,EN2,FF1,FF2
*      WRITE(6,927)HR,ETAH,VH,ISH,HM,TOR1,TOR2,EN1,EN2,FF1,FF2
* 927  FORMAT(/2ØX,34H7KW PARALLEL HYBRID VARIABLES ARE:,/35X25HHYBRID/MO
*     CTOR SPEED RATIO=,F6.3,/35X2ØHCOUPLING EFFICIENCY=,F5.1,1H%,/35X17H
*     CENGAGEMENT SPEED=,F5.1,5HKM/HR,/35X22HTRANSMISSION POSITION=,I2,
*     C' GEAR',/35X,'HYBRID MASS=',F5.1,3H KG,/35X,'MAX TORQUE=',F5.2,/35
*     CX,'TORQUE AT MAX RPM=',F5.2,/35X,'RPM FOR MAX TORQUE=',F7.1,/35X,'
*     CMAX RPM=',F7.1,/35X,'FUEL FLOW AT MAX TORQUE=',/35X,'FUEL FLOW AT
*     CMAX RPM=')
*      COEF3=(TØR2-TOR1)/(EN1**2-2.*EN1*EN2+EN2**2)
*      COEF2=-2.*COEF3*EN1
*      COEF1=TOR1+COEF3*EN1**2
* 7Ø   IS=ISH
* 71   CONTINUE
C
C     PROGRAM IS NOW READING INPUTTED DRIVING CYCLE SPEED SCHEDULE DATA.
C     FIRST CARD- TIME INCREMENT(T), NUMBER OF DATA POINTS(NDATA). FOL-
C     LOWING CARDS- SPEED SCHEDULE(VX) IN 18F4.1. LAST CARD- CONVERSION
C     FACTOR)Ø IF VX IN MPH, 1 IF VX IN KPH (CONV).
C
      READ(1,*)T,NDATA
      NNDATA=NDATA/18+1
      DO 8Ø J=1,NNDATA
 8Ø   READ(5,9Ø1)(VX(18*(J-1)+K),K=2,19)
      READ(1,*)CONV
      PRINT*, 'CONV',CONV
      IF(CONV.NE.Ø.)GO TO 82
 81   DO 81Ø1 J=1,NDATA
 81Ø1 VX(J+1)=VX(J+1)*1.6Ø2
 82   NNNDATA=NDATA/6Ø+1
C
C     ENTER PROGRAM OPTION. FIRST CARD- Ø IF SYSTEM EVALUATION, 1 IF
C     SYSTEM DESIGN. NEXT CARD)IF IPROG=1 - MAXIMUM ALLOWABLE BATTERY
C     DISCHARGE(DSMAX), AND MAXIMUM ALLOWABLE SPEED SCHEDULE DEVIATION
C     (DVMAX).
C
      READ(1,*)IPROG
      IF(IPROG.NE.Ø)GO TO 82Ø2
 82Ø1 WRITE(6,93Ø)
 93Ø  FORMAT(/2ØX33HSYSTEM EVALUATION OPTION SELECTED)
      GO TO 82Ø3
 82Ø2 READ(1,*)DSMAX,DVMAX
      WRITE(6,931)DSMAX,DVMAX
 931  FORMAT(/2ØX35HSYSTEM DESIGN OPTION SELECTED WITH:/35X22HMAX BATTER
     CY DISCHARGE=,F5.1,2H (,/35X2ØHMAX SPEED DEVIATION=,F5.1,6H KM/HR)
 82Ø3 DEV=Ø.
```

```
      DIS=Ø.
 83   VV1=Ø.
      V(1)=Ø.
      VX(1)=Ø.
      W=Ø.
      WB=Ø.
      WH=Ø.
      D=Ø.
      KK=1
      PMAX=PRATM*IPMAX
      MM=5.75**ALOG1Ø(PRATM)*21.5+HM
      M=(MM+BM+FM)/.74+.85*PM
      AHT=Ø.
      IF(DIS.EQ.Ø.)GO TO 83Ø2
 83Ø1 FA=(M/M1)**.5*FA
 83Ø2 M1=M
  DIS=Ø.
      DO 16Ø II=1,NNNDATA
      WRITE(6,924)
 924  FORMAT(1H1,' TIME  VELO-SCH  VELO-ACT  DEVIATION  F-ROLL  F-AIR
     C F-ACCEL  INPUT-POWER  GEAR  SHAFT-RPM  CONTROLLER  MTR  ARM',
     C ' BAT DISCHARGE')
      WRITE(6,9241)
 9241 FORMAT(1X,' (SEC)  (KM/HR)  (KM/HR)  (KM/HR)   (NT)   (NT)
     C(NT)   (MTR) (HYB) SELECT (MTR)(HYB) STEP/FIELD  VOLTS  AMPS
     C  (%)')
      DO 16Ø III=1,6Ø
      I=III+II*6Ø-59
      IF(VX(I).GE.99.9)GO TO 17Ø
* 85   VBAT=(73.1-4.32*DIS*DIS)*VNOM/72.
      V(I)=VX(I)
      KKK=Ø
 9Ø   VV=V(I)*.2778
      DELTAV=.Ø2
      A=Ø.
      VLT=Ø.
      MS=Ø.
      MSH=Ø.
      MMM=Ø
*      PRQDH=Ø.
*     PAVL=Ø.
      MCF=1.Ø2
      VVA=(VV1+VV)/2.
      IF(IS.EQ.Ø)GO TO 92
 91   CALL MTRSPD(VVA,RR,AR,GR,UPSHFT,DNSHFT,IS,KK,MS)
      MCF=MCF+.ØØØ294*(AR*GR(KK)/RR)**2.
 92   FR=(CR+.ØØØØØØ2Ø9*VVA**2.8)*M*9.81
      FAIR=VVA**2.*176.4*FA*CD/(273.+TMP)
      FACC=M*(VV-VV1)/T*MCF
      F=FR+FAIR+FACC
      P=F*VVA/1ØØØ.
      IF(VVA.EQ.Ø.)GO TO 153
 9ØØ2 PSPD=V(I)/VMAX*1ØØ.
      PP=P/PMAX*1ØØ.
      IF(PP.EQ.Ø.)GO TO 92Ø2
```

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9201 ETAA=95.8-(.01217*PSPD*PSPD+.8879*PSPD+4.261)/ABS(PP)
9202 IF(IS.NE.0)GO TO 9204
9203 MS=BSPD
     CALL TRNSEFF(P,ETAA,PRATT,VVA,RR,AR,BSPD,TSTP,ITSTP,ETAT,ETA)
     GO TO 100
9204 IF(PP.EQ.0.)GO TO 153
9205 PSPDT=PSPD*GR(KK)/GR(IS)
     IF(GR(KK).GE.1.)GO TO 94
93   EMAX=EXP(.03*(1.-1./GR(KK)))
     GO TO 95
94   EMAX=EXP(.03*(1.-GR(KK)))
95   ETA=EMAX*(99.-(.004005*PSPDT*PSPDT+.1849*PSPDT-1.565)/ABS(PP))
100  IF(PP.LE.0.)GO TO 102
101  PRQD=P/ETAA/ETA*10000.
     GO TO (110,1101,1101)CTYP
102  PAVL=P*ETAA*ETA/10000.
     GO TO 151
* 110 CALL VSTEP(PRQD,MS,RARM,KMOT,VBAT,ICSTP,CSTP,A,PAVL,AMAX,PRATM,
*    CMSTP,IMSTP,ETAM,MMM,RBAT,VLT,IHYB,HR,ETAH,PRQDH,V(I),VH,MTYP,RFLD,
*    CCOEF1,COEF2,COEF3)
     GO TO 111
* 1101 CALL VCHOP(MTYP,RARM,RFLD,KMOT,AMAX,PRATM,IMSTP,MSTP,ETAM,RBAT,VBA
*    CT,IHYB,HR,ETAH,VH,PRQD,MS,V(I),A,VLT,PAVL,PRQDH,COEF1,COEF2,COEF3)
111  IF(ABS((PAVL-PRQD)/M/V(I)).GT..0001)DELTAV=.5
112  IF(KKK.EQ.2)GO TO 121
118  IF(PAVL.LE.PRQD)GO TO 120
119  V(I)=V(I)+DELTAV
     KKK=1
     GO TO 90
120  IF(KKK.LE.1)GO TO 121
121  IF(PAVL.GE.PRQD)GO TO 152
122  V(I)=V(I)-DELTAV
     KKK=2
     GO TO 90
151  WB=WB+T/3600.*PAVL
     GO TO 153
152  W=W+T/3600.*PAVL
     WH=WH+T/3600.*PRQDH
153  IT=I*T-T
     VV1=VV
     PRQDE=PAVL-PRQDH
     IF(V(I).GE.VH.AND.IHYB.EQ.1)MSH=MS*HR
     D=D+VVA*T/1000.
     DEV=V(I)-VX(I)
     WRITE(6,918)IT,VX(I),V(I),DEV,FR,FAIR,FACC,PRQDE,PRQDH,KK,MS,MSH,M
    CMM,FLD,VLT,A,DIS
918  FORMAT(1XI4,F9.1,2F10.1,F10.0,2F8.0,F7.1,F6.1,I5,F8.0,F6.0,I4,F7.0
    C,F7.1,F6.0,F12.4)
     IF(MMM.EQ.0)MMM=1
155  CALL BATDIS(TMP,A,AHT,T,IT,DIS,CSTP(MMM),VNOM,BM)
     IF(IPROG.EQ.0)GO TO 160
     IF(DIS.LE.DSMAX)GO TO 1553
1551 BM=BM+100.
     DO 1552 LL=1,ICSTP
1552 RBAT(LL)=RBAT1(LL)*BM1/BM
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```
      PRINT*,'   TOTAL TIME= ',IT,' SECS'
      WRITE(6,928)BM
928   FORMAT(/20X92H''''' CYCLE TERMINATED DUE TO INSUFFICIENT BATTERY C
     CCAPACITY TO MEET RANGE REQUIREMENTS ''''',/35X24HNEXT ITERATION WIL
     CL USE:,/40X14HBATTERY MASS= ,F5.0)
      GO TO 83
1553  IF(V(I).GE.87. .OR.IT.LE.120)GO TO 160
156   PRATM=PRATM+1.
      R=PRATM/(PRATM-1.)
      BM=BM*R**.5
      DO 157  L=1,ICSTP
157   RBAT(L)=RBAT1(L)*BM1/BM
      RFLD=RFLD/R
      RARM=RARM/R
      KMOT=KMOT/R
      AMAX=AMAX*R
      PRINT*,'   TOTAL TIME= ',IT,' SECS'
      WRITE(6,925)PRATM,BM
925   FORMAT(25X81H''''' CYCLE TERMINATED DUE TO INSUFFICIENT POWER TO M
     CEET POWER REQUIREMENTS ''''',/35X24HNEXT ITERATION WILL USE:/40X13
     CHMOTOR POWER= ,F4.1/40X14HBATTERY MASS= ,F5.0)
      GO TO 83
160   CONTINUE
170   PRINT*,' TOTAL CYCLE TIME (MIN) ='
      TIME=T*(IT-1)/60.
      WRITE(6,919)TIME
919   FORMAT(F10.4)
      PRINT*,' TOTAL CYCLE DISTANCE (KM) ='
      WRITE(6,919)D
      WM=W-WH
      PRINT*,' TOTAL MOTOR INPUT ENERGY (KW-HR) ='
      WRITE(6,919)WM
      PRINT*,' TOTAL ENGINE INPUT ENERGY (KW-HR) ='
      WRITE(6,919)WH
      PRINT*,' TOTAL REGENERATION ENERGY AVAILABLE (KW-HR) ='
      WRITE(6,919)WB
      PRINT*,' BATTERY DISCHARGE AT END OF CYCLE (() ='
      WRITE(6,919)DIS
      GAS=WH*.56*FCOST/D
      ELECT=WM*ECOST/.6/D
      PRINT*,' AVG CYCLE ELECTRICAL COST ($/KM) ='
      WRITE(6,919)ELECT
      PRINT*,' AVG PETROLEUM FUEL COST ($/KM) ='
      WRITE(6,919)GAS
      IF(IPROG.EQ.0)GO TO 172
      PRINT*,' FINAL VEHICLE PARAMETERS ARE:'
      PRINT*,'     MOTOR POWER= ',PRATM,'  BATTERY MASS= ',BM
      PRINT*,'     TOTAL MASS= ',M,'  FRONTAL AREA= ',FA
172   END
      SUBROUTINE MTRSPD(VVA,RR,AR,GR,UPSHFT,DNSHFT,IS,K,RMS)
      DIMENSION GR(10)
C
C     THIS SUBROUTINE COMPUTES MOTOR SPEED FOR MULTI-SPEED TRANSMISSIONS
C     AND DRIVING CYCLE REQUIREMENTS.
C
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 100   RMS=VVA*9.549/RR*AR*GR(K)
       IF (RMS.LE.UPSHFT)GO TO 103
 101   IF(K.GE.IS)GO TO 106
 102   K=K+1
       GO TO 100
 103   IF (RMS.GE.DNSHFT)GO TO 106
 104   IF(K.LE.1)GO TO 106
 105   K=K-1
       GO TO 100
 106   RETURN
       END
*       SUBROUTINE VCHOP(MTYP,RARM,RFLD,RKMOT,AMAX,PRATM,IMSTP,RMSTP,ETAM,
*      CRBAT,VBAT,IHYB,HR,ETAH,VH,P,RMS,V,A,VLT,PAVL,PRQDH,COEF1,COEF2,COE
*      CF3)
       DIMENSION RMSTP(10),ETAM(10,30)
C
C      THIS SUBROUTINE CALCULATES MOTOR POWER DEVELOPED AND CURRENT
C      REQUIRED FOR SCR CHOPPER VOLTAGE CONTROLLERS WITH DC MOTORS. IT
C      ASSUMES 1.5 VOLTS JUNCTION LOSS AND 3( COPPER LOSS.
C
       KK=0
       C=RMS*RKMOT
*       PAVLH=0.
*       PRQD=P*1000.
*       IF(IHYB.NE.1)GO TO 423
*       IF(PRQD.LE.0.)GO TO 423
*       IF(V.LT.VH)GO TO 423
* 414   HRS=RMS*HR
*       TORK=COEF1+COEF2*HRS+COEF3*HRS**2
*       PAVLH=(TORK*HRS*.7457/5252.)*ETAH/100.
*       IF(PAVLH.GE.P)GO TO 421
*       PRQDH=PAVLH
*       PRQD=PRQD-PRQDH*1000
*       GO TO 423
* 421   PRQDH=P
*       PAVL=P
*       RETURN
 423   CALL MTREFF(PRQD,PRATM,RMS,RMSTP,IMSTP,ETAM,ETA)
       IF(MTYP.NE.0)GO TO 402
 401   EAIA=PRQD/ETA*100.*C/(RFLD+RARM*RFLD/(RFLD-C))
       IF(EAIA.LT.PRQD)EAIA=PRQD
       VLT=(EAIA*RARM*RFLD*RFLD/C/(RFLD-C))**.5
       VMAX=AMAX*RARM*RFLD/(RFLD-C)
       A=EAIA*RFLD/VLT/C
       GO TO 403
 402   RTOT=RARM+RFLD
       EAIA=PRQD*C/ETA/(C+RTOT)
       IF(EAIA.LT.PRQD)EAIA=PRQD
       A=(EAIA/C)**.5
       VMAX=AMAX*(RBAT+1.03*(RTOT+C))+1.5
       VLT=A*VMAX/AMAX
 403   IF(VLT.GT.VMAX)KK=1
       VLT=VMAX
       A=AMAX
       IF(VLT.GT.VBAT)GO TO 406
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 404   IF(KK.NE.Ø)GO TO 4Ø7
 405   PAVL=P
       RETURN
 406   VLT=VBAT
 407   IF(MTYP.NE.Ø)GO TO 4Ø9
 408   EAIA=C*VLT*VLT/RARM/RFLD*(1.-C/RFLD)
       A=EAIA/C/VLT*RFLD
       GO TO 41Ø
 409   EAIA=(VLT-1.5)/(RBAT+1.Ø3*(RTOT+C))**2.*C
       A=(EAIA/C)**.5
 410   CALL MTREFF(EAIA,PRATM,RMS,RMSTP,IMSTP,ETAM,ETA)
       IF(MTYP.NE.Ø)GO TO 412
 411   PAVL=ETA*(EAIA+A*A*RARM+VLT*VLT/RFLD)*1ØØØØØ.
       GO TO 413
 412   PAVL=ETA*(EAIA+A*A*RTOT)/1ØØØØØ.
 413   IF(PAVL.GT.EAIA/1ØØØ.)PAVL=EAIA/1ØØØ.
* 416   PAVL=PAVLH+PAVL
 417   RETURN
       END
*       SUBROUTINE VSTEP(P,RMS,RARM,RKMOT,VBAT,ICSTP,CSTP,A,PAVL,AMAX,PRAT
*      CM,RMSTP,IMSTP,ETAM,M,RBAT,VLT,IHYB,HR,ETAH,PRQDH,V,VH,MTYP,RFLD,
*      CCOEF1,COEF2,COEF3)
       DIMENSION CSTP(5),RMSTP(1Ø),ETAM(1Ø,3Ø),RBAT(5)
C
C      THIS SUBROUTINE CALCULATES MOTOR POWER DEVELOPED AND CURRENT
C      REQUIRED FOR FINITE STEP VOLTAGE CONTROLLERS WITH DC MOTORS.
C
*       PRQD=P
*       PAVLH=Ø.
*       IF(IHYB.NE.1.OR.V.LT.VH)GO TO 523
*       IF(PRQD.LE.Ø.)GO TO 523
*       HRS=RMS*HR
*       TORK=COEF1+COEF2*HRS+COEF3*HRS**2
*       PAVLH=(TORK*HRS*.7457/5252.)*ETAH/1ØØ.
*       IF(PAVLH.GE.P)GO TO 521
*       PRQD=P-PAVLH
*       PRQDH=PAVLH
*       GO TO 523
* 521   PRQDH=P
*       PAVL=P
*       RETURN
 523   MM=Ø
       IF(MTYP.EQ.Ø.AND.RMS.LT.1ØØØ.)RMS=1ØØØ.
 5Ø1   M=M+1
       C=RMS*RKMOT
       DV=A*RBAT(M)
 5Ø11  VLT=CSTP(M)*VBAT-DV
       IF(MTYP.NE.Ø)GO TO 5112
 5111  EAIA=C*VLT*VLT/RARM/RFLD*(1.-C/RFLD)
       A=EAIA*RFLD/VLT/C
       GO TO 5113
 5112  RTOT=RFLD+RARM
       EAIA=((VLT-VLT*C/(RTOT+C))/RTOT)**2.*C
       A=(EAIA/C)**.5
 5113  DV2=A*RBAT(M)
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      IF(ABS(DV2-DV).LE.Ø.3)GO TO 5Ø13
 5Ø12 DV=DV2
      GO TO 5Ø11
 5Ø13 CALL MTREFF(EAIA,PRATM,RMS,RMSTP,IMSTP,ETAM,ETA)
      IF(MTYP.NE.Ø)GO TO 5212
 5211 PAVL=ETA*(EAIA+A*A*RARM+VLT*VLT/RFLD)/1ØØØØØ.
      GO TO 5213
 5212 PAVL=ETA*(EAIA+A**2.*RTOT)/1ØØØØØ.
 5213 IF(PAVL.GT.EAIA/1ØØØ.)PAVL=EAIA/1ØØØ.
 5Ø15 IF(MM.NE.Ø)GO TO 5Ø8
 5Ø2  IF(M.GT.1.AND.A.GT.AMAX)GO TO 5Ø6
 5Ø4  IF(PAVL.GE.(PRQD*.8))GO TO 5Ø61
 5Ø5  IF(M.LT.ICSTP)GO TO 5Ø1
 5Ø61 IF(PAVL.GE.PRQD)GO TO 5Ø7
      IF(M.NE.ICSTP)GO TO 5Ø8
 5Ø6  M=M-2
      MM=1
      GO TO 5Ø1
* 5Ø8  PAVL=PAVL+PAVLH
      RETURN
 5Ø7  PAVL=P
      RETURN
      END
      SUBROUTINE MTREFF(EAIA,PRATM,RMS,RMSTP,IMSTP,ETAM,ETA)
      DIMENSION ETAM(1Ø,3Ø),RMSTP(1Ø)
C
C     THIS SUBROUTINE PERFORMS A BILINEAR INTERPOLATION FOR MOTOR
C     EFFICIENCY(ETAM) AS INPUTTED FOR DISCRETE VALUES OF MOTOR SPEED
C     (RMSTP) AND PERCENT OF RATED POWER(PP).
C
      PP=EAIA/PRATM/1Ø.
      K=1
      KK=1
 6ØØ  IF(RMS.LE.RMSTP(K))GO TO 6Ø1
 6Ø1  IF(K.GE.IMSTP)GO TO 6Ø3
 6Ø2  K=K+1
      GO TO 6ØØ
 6Ø3  IF(PP.LE.(KK*1Ø.))GO TO 6Ø5
 6Ø31 IF(KK.GE.3Ø)GO TO 6Ø5
 6Ø4  KK=KK+1
      GO TO 6Ø3
 6Ø5  IF(K.NE.1)GO TO 6Ø7
 6Ø6  IF(KK.EQ.1)GO TO 6Ø8
      GO TO 6Ø9
 6Ø7  CC=(RMS-RMSTP(K-1))/(RMSTP(K)-RMSTP(K-1))
      ETA2=(ETAM(K,KK)-ETAM(K-1,KK))*CC+ETAM(K-1,KK)
      IF(KK.EQ.1)GO TO 61Ø
         GO TO 611
 6Ø8  ETA=ETAM(1,1)
      RETURN
 6Ø9  ETA1=ETAM(K,KK-1)
      ETA2=ETAM(K,KK)
      GO TO 612
 61Ø  ETA=ETA2
      RETURN
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 611  ETA1=(ETAM(K,KK-1)-ETAM(K-1,KK-1))*CC+ETAM(K-1,KK-1)
 612  ETA=(ETA2-ETA1)*(PP-(KK-1)*10.)/10.+ETA1
      RETURN
      END
      SUBROUTINE TRNSEFF(P,ETAA,PRATT,VVA,RR,AR,BSPD,TSTP,ITSTP,ETAT,ETA
     C)
      DIMENSION TSTP(10),ETAT(10,20)
C
C     THIS SUBROUTINE PERFORMS A BILINEAR INTERPOLATION FOR CVT EFFICI-
C     ENCY(ETAT) AS INPUTTED FOR DISCRETE VALUES OF SPEED RATIOS(TSTP)
C     AND PERCENT RATED POWER(PP).
C
      PP=P*ETAA/PRATT
      DSS=9.549*VVA/RR*AR
      SR=DSS/BSPD
      K=1
      KK=1
 700  IF(SR.LE.TSTP(K))GO TO 703
 701  IF(K.LT.ITSTP)GO TO 703
 702  K=K+1
      GO TO 700
 703  IF(PP.LE.(KK*5.))GO TO 705
 7031 IF(KK.NE.20)GO TO 705
 704  KK=KK+1
      GO TO 703
 705  IF(K.NE.1)GO TO 707
 706  IF(KK.EQ.1)GO TO 708
      GO TO 709
 707  CC=(SR-TSTP(K-1))/(TSTP(K)-TSTP(K-1))
      ETA2=(ETAT(K,KK)-ETAT(K-1,KK))*CC+ETAT(K-1,KK)
      IF(KK.EQ.1)GO TO 710
      GO TO 711
 708  ETA=ETAT(1,1)
      RETURN
 709  ETA1=ETAT(K,KK-1)
      ETA2=ETAT(K,KK)
      GO TO 712
 710  ETA=ETA2
      RETURN
 711  ETA1=(ETAT(K,KK-1)-ETAT(K-1,KK-1))*CC+ETAT(K-1,KK-1)
 712  ETA=(ETA2-ETA1)*(PP-(KK-1)*5.)/5.+ETA1
      RETURN
      END
      SUBROUTINE BATDIS(TMP,A,AHT,T,IT,DIS,CSTP,VNOM,BM)
C
C     THIS SUBROUTINE COMPUTES TOTAL BATTERY DISCHARGE)( (DIS) FOR LEAD
C     ACID BAT ERIES OF GOLF-CART TYPE CONSTRUCTION. IT IS TEMPERATURE
C     CORRECTED AND USES A MODIFIED FRACTIONAL-UTILIZATION METHOD WITH
C     CORRECTIONS FOR CHANGING CURRENTS AND RECUPERATION PERIODS.
C
      A=A*CSTP*350./BM*VNOM/72.
      AHT=AHT+A*T/3600.
      AH=(195.-.633*A+.000913*A*A)*(.014*TMP+.65)
      AAVG=AHT/IT*3600.
      AHA=(195.-.633*AAVG+.000913*AAVG*AAVG)*(.014*TMP+.65)
```

```
      IF(A.NE.Ø.)GO TO 8Ø2
8Ø1   RA=Ø.
      GO TO 8Ø5
8Ø2   IF(A.LE.AAVG)GO TO 8Ø4
8Ø3   RA=AAVG/A
      GO TO 8Ø5
8Ø4   RA=A/AAVG
8Ø5   DIS=(AHT/AH*RA+AHT/AHA*(1.-RA))*1ØØ.
      RETURN
      END
```

TIME (SEC)	VELO-SCH (KM/HR)	VELO-ACT (KM/HR)	DEVIATION (KM/HR)	F-ROLL (NT)	F-AIR (NT)	F-ACCEL (NT)	INPUT-POWER (MTR)	INPUT-POWER (HYB)	GEAR SELECT	SHAFT-RPM (MTR)	SHAFT-RPM (HYB)	CONTROLLER STEP	CONTROLLER FIELD	MTR VOLTS	ARM AMPS	BAT DISCHARGE (%)
421	68.9	50.6	-18.3	134.	94.	0.	0.0	3.6	3	2022.	5400.	3	0.	4.1	8.	3.8754
422	68.9	50.6	-18.3	134.	94.	0.	0.0	3.6	3	2022.	5400.	3	0.	4.1	8.	3.8751
423	68.9	50.6	-18.3	134.	94.	0.	0.0	3.6	3	2022.	5400.	3	0.	4.1	8.	3.8747
424	68.9	50.6	-18.3	134.	94.	0.	0.0	3.6	3	2022.	5400.	3	0.	4.1	8.	3.8744
425	68.9	50.6	-18.3	134.	94.	0.	0.0	3.6	3	2022.	5400.	3	0.	4.1	8.	3.8740
426	68.9	50.6	-18.3	134.	94.	0.	0.0	3.6	3	2022.	5400.	3	0.	4.1	8.	3.8737
427	56.1	50.6	-5.5	134.	94.	-6.	0.0	3.5	3	2022.	5399.	0	0.	0.0	0.	3.8734
428	56.1	50.6	-5.5	134.	94.	-8.	0.0	3.5	3	2021.	5397.	0	0.	0.0	0.	3.9159
429	56.1	50.6	-5.5	134.	94.	0.	0.0	3.6	3	2021.	5396.	3	0.	3.4	7.	3.9147
430	56.1	50.5	-5.5	134.	94.	-8.	0.0	3.5	3	2021.	5395.	0	0.	0.0	0.	3.8771
431	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.3	5.	3.9130
432	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.5	5.	3.8947
433	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.5	5.	3.8923
434	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.5	5.	3.8913
435	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8905
436	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8896
437	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8887
438	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8879
439	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8870
440	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8862
441	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8853
442	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8845
443	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8837
444	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.6	5.	3.8829
445	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8821
446	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8813
447	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8805
448	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8797
449	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8789
450	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8781
451	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8774
452	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8766
453	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8759
454	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8751
455	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8744
456	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.7	5.	3.8737
457	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	5.	3.8729
458	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	5.	3.8722
459	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	5.	3.8715
460	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	5.	3.8708
461	56.1	50.5	-5.5	13[illegible]	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	5.	3.8701
462	56.1	50.5	-5.5	[illegible]4.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8694
463	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8687
464	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8681
465	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8674
466	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8667
467	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8661
468	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8654
469	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.8	6.	3.8648
470	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8641
471	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8635
472	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8629
473	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8622
474	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8616
475	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8610
476	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8604
477	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8598
478	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8592
479	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8586
480	56.1	50.5	-5.5	134.	94.	0.	[illegible].0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8580

TIME (SEC)	VELO-SCH (KM/HR)	VELO-ACT (KM/HR)	DEVIATION (KM/HR)	F-ROLL (NT)	F-AIR (NT)	F-ACCEL (NT)	INPUT-POWER (MTR)	INPUT-POWER (HYB)	GEAR SELECT	SHAFT-RPM (MTR)	SHAFT-RPM (HYB)	CONTROLLER STEP	CONTROLLER FIELD	MTR VOLTS	ARM AMPS	BAT DISCHARGE (%)
481	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8575
482	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8569
483	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8563
484	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8557
485	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	2.9	6.	3.8552
486	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	3.0	6.	3.8546
487	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	3.0	6.	3.8541
488	56.1	50.5	-5.5	134.	94.	0.	0.0	3.6	3	2020.	5394.	2	0.	3.0	6.	3.8536

TOTAL CYCLE TIME (MIN) =
8.1167
TOTAL CYCLE DISTANCE (KM) =
7.2099
TOTAL MOTOR INPUT ENERGY (KW-HR) =
0.1843
TOTAL ENGINE INPUT ENERGY (KW-HR) =
0.3961
TOTAL REGENERATION ENERGY AVAILABLE (KW-HR) =
0.0000
BATTERY DISCHARGE AT END OF CYCLE (() =
3.8530
AVG CYCLE ELECTRICAL COST ($/KM) =
0.0021
AVG PETROLEUM FUEL COST ($/KM) =
0.0108
$ EOJ
FOUNDS job terminated at 24-SEP-1983 13:42:57.23

Accounting information:

Buffered I/O count:	73	Peak working set size:	235
Direct I/O count:	163	Peak page file size:	315
Page faults:	3993	Mounted volumes:	0
Elapsed CPU time:	0 00:01:09.36	Elapsed time:	0 00:01:42.76

Vita

David Boyd Founds was born on 28 June 1958 in Seattle Washington. Upon graduation from high school in Anchorage, Alaska in 1976, he accepted an Air Force ROTC scholarship to the University of Idaho. In 1980, he received a Bachelor of Science degree in Mechanical Engineering and his commission in the Air Force. He then entered the Air Force Institue of Technology in June 1980.

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Lynn E. Wolaver

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Dean for Research and Professional Development

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

electric cars   batteries

hybrid cars

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Interest in nonpetroleum fueled ground vehicles led Stafford to develop the computer code Electric Vehicle Simulation (EVSIM). EVSIM was designed to predict the performance of current electric vehicles or to be used in the design of electric/hybrid vehicles. Before EVSIM could be used it needed to be verified by comparing it predictions to the results of a vehicle test. It was also desired to improve the code's ability to model several types of Internal Combustion Engines that may be used in future hybrid vehicles. (continu)

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The approach taken was to test the components of the hybrid vehicle separetly prior to testing the whole vehicle. This was done to verify separte sections of EVSIM prior to a systems run. The results of these comparisons and the system comparisons are included with recommended changes to EVSIM.

END

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